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**ENGINEERING PHYSICS AND MATHEMATICS DIVISION PROGRESS REPORT
FOR PERIOD ENDING SEPTEMBER 30, 1987**

F. C. Maienschein, Director

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PREFACE

The primary purpose of this report is to provide an archival record of the activities of the Engineering Physics and Mathematics Division during the period June 30, 1985 through September 30, 1987.

As has become the custom in the series of progress reports, which are identified on the previous page, coverage of our research is provided primarily through abstracts of journal articles, reports, and presentations. In addition, the progress reports include appendices which summarize publications, presentations, and other professional activities of the division staff members.

The content of this report is organized following the division of our research among four sections. The division organization chart, as of January 1, 1988, is included at the back of the report.

Mathematical Sciences. Work in Mathematical Sciences continues to include applied mathematics research, statistics research, and computer science. The statistics research is reoriented to include computational statistics as well as applications to life sciences and physical sciences. Computer science research now regularly features the use of multiprocessors with local or shared memory.

Nuclear-Data Measurement and Evaluation. Nuclear-data measurements and evaluations continue for fusion reactors, fission reactors, and other nuclear systems. The work of this section continues to depend upon the operation of the Oak Ridge Electron Linear Accelerator, which has achieved its highest output ever in short pulses during this period.

Systems Analysis and Shielding. Now included in this section are long-standing studies of fission-reactor shields through experiments and related analysis, of accelerator shielding, and of fusion-reactor neutronics. Expanded attention has been devoted to diverse aspects of shielding and related survivability of weapons systems in space. An expanded analysis effort is in place for reactor physics, shielding, thermal-hydraulics, and related aspects of the Advanced Neutron Source. Reliability and related human factor studies are also included in this section. At the end of the section are included papers which have been published in risk assessment, mostly by subcontractors of ORNL working through a division staff member.

Machine Intelligence and Mathematical Modeling. Work in Machine Intelligence continues to feature the development of an autonomous robot. Expanded cooperation with the Instrumentation and Controls and the Fuel Recycle divisions in this and other activities in teleoperations and robotics has taken place through the Robotics and Intelligent Systems Program (RISP). Automated sensitivity analyses and quantitative determinations of the reliability of results from simulation have been developed with applications primarily in nuclear waste isolation, radiation dosimetry, and energy economy modeling.

Engineering Physics Information Center. The last descriptive part of this report reflects the work in our Engineering Physics Information Center, which again concentrates primarily upon radiation-shielding methods and related data. The Radiation Shielding Information Center (RSIC) completed its twenty-fifth year of operation during this period. The Technical Data Management Center (TDMC) was operated for NRC from 1976 to 1987. Closeout activities for TDMC will extend into 1988.

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Section 1

MATHEMATICAL SCIENCES

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1.0. INTRODUCTION

R. C. Ward

Activities in the mathematical sciences during the report period continued to be divided in near equal proportions between basic research and collaboration with other scientists at the Oak Ridge DOE facilities. Major disciplines covered by these research and consulting activities include statistics, computer science, and mathematics.

Parallel computing remained the focus of our basic research program in computer science. Significant progress was made on performing many basic matrix computations on both shared-memory and distributed-memory multiprocessors. Highlights include the development of efficient parallel algorithms for the solution of three important classes of problems — large sparse positive definite systems of linear equations, non-symmetric systems of linear equations, and triangular systems. The latter problem was thought to be inherently serial under certain conditions until this work. In addition, new results were obtained which limit the computation and storage complexity for solving sparse nonsymmetric linear systems from finite element problems. This development gives to nonsymmetric problems many of the computational advantages that have previously been enjoyed only by symmetric positive definite systems.

Research in mathematics has continued to emphasize moving boundary problems, specifically phase change problems involving conduction and convection. An algorithm has been developed for Cray supercomputers that solves three-dimensional moving boundary problems in a rectangular parallelepiped with a wide variety of initial and boundary conditions. This is the first vectorized code for solving such general problems. Other highlights include the use of fractals to model electrical current across rough surfaces, the development of a mathematical model for electroplating along with an efficient method for its solution, and the mathematical modeling of solidification with void formation.

In statistics, a new research project was initiated in the design and analysis of computational experiments to join existing projects in computational statistics and biostatistics. Our efforts in this new project have been focused on developing the necessary tools and approaches to produce fast approximations with confidence regions to the output of large-scale computer codes. Among our significant accomplishments in computational statistics has been the development of a methodology for assisting the modeler in the determination of the important variables in a model and the applications of sparse matrix technology to important statistical computing problems. Highlights of our biostatistics research has been the development of new methods of analysis for sigmoidal dose-response curves and maximum likelihood estimation procedures for nonlinear cytogenetic dose-response curves.

Funding support for our basic research projects were received from the Applied Mathematical Sciences Program and the Office of Health and Environmental Research (both in the DOE Office of Energy Research), the AFOSR Computational Mathematics Program, and the ORNL Exploratory Studies Program. Support, from outside organizations to extend our basic research to specific applications of interest to them, was received from NASA Marshall Space Flight Center's Materials Processing Program, Martin Marietta Aerospace, and the Tennessee Valley Authority. Most technical organizations inside Martin Marietta Energy Systems also used our expertise in mathematics, statistics, or computer science during the reporting period.

Additions to our Research Computing Facility have significantly improved our capability to carry out research in all areas of the mathematical sciences. An Intel iPSC/d6 was added in July 1985, and a Sequent Balance 8000 was added in February 1986. The Intel computer is a hypercube parallel computer having 64 asynchronous processors and 32 megabytes of memory. It serves strictly as a research tool in the exploration of computational algorithms for message-passing parallel computers having only distributed memory. The Sequent computer is a bus-based parallel computer with 8 asynchronous processors sharing 8 megabytes of memory. It provides a computer for testing parallel algorithms for a shared-memory environment as well as some needed production CPU cycles for the expanding computational and communication needs of the section.

During the reporting period, the section has undergone several staff changes. David Gosslee, who served as leader of our Statistics Group for many years, retired with Darryl Downing transferring from the Computing and Telecommunications Division to become the new leader. Alan George, formerly Dean of the Mathematics Faculty at the University of Waterloo, joined our Computer Science Group and the Departments of Mathematics and Computer Science at the University of Tennessee as a Distinguished Scientist. Our Computer Science Group was also considerably strengthened by the addition of Young Etheridge, Chuck Romine, and Pat Worley. Dawn Human of our secretarial staff transferred into another section of our division with Joyce Nave replacing her.

Applied Mathematics

1.1

VOID FORMATION IN SOLIDIFICATION

V. Alexiades

(Abstract of oral presentation given at the EQUADIFF 87, International Conference on Differential Equations, Xanthi, Greece, August 24-28, 1987)

Most materials contract upon solidification, causing the creation of voids (vapor bubbles) within the material, which in turn affects the heat transfer and subsequent solidification. Such phenomena are usually ignored without justification, other than that problems become too complicated.

Our interest arises from Latent Heat Thermal Energy Storage processes for the Space Station, where the proposed material undergoes a 30% density change and therefore its effects cannot be ignored. Our first attempts at understanding such phenomena will be discussed, including a steady-state two-dimensional model designed to capture some of the main effects.

Research sponsored by NASA/Lewis.

1.2

MATHEMATICAL MODELING OF LASER INDUCED ULTRARAPID MELTING AND SOLIDIFICATION

V. Alexiades	J. B. Drake
G. A. Geist	G. E. Giles*
A. D. Solomon	R. F. Wood†

(Abstract of ORNL-6129, March 1986)

Mathematical and numerical aspects of laser induced phase change modeling are discussed. Several numerical formulations, including explicit and implicit enthalpy, adaptive grid finite volume and front tracking are derived and results are presented. In addition, a novel hyperbolic formulation is explored analytically and numerically. The explicit enthalpy approach allows the

greatest flexibility and efficiency in modeling problems with complicated phase transitions.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and by National Aeronautics and Space Administration.

*Computing and Telecommunications Division.

†Solid State Division.

1.3

CRITICAL RADIUS FOR NUCLEATION

V. Alexiades A. D. Solomon

(Abstract of ORNL/TM-9931, April 1986)

The free energy of formation and the critical radius for homogeneous nucleation of a spherical nucleus in supercooled liquid, at given temperature and ambient pressure, are determined, taking fully into account surface area, curvature, and pressure effects. We allow the specific heats and densities of the two phases to be different and all thermophysical properties to be temperature dependent. In the simple case in which classical nucleation theory is valid, our results predict a critical radius of about 40% larger than the classical value, and an activation energy barrier of almost three times larger than the classical value.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and by Microgravity Science and Applications Division of the National Aeronautics and Space Administration.

1.4

THE FORMATION OF A SOLID NUCLEUS IN SUPERCOOLED LIQUID, PART II

V. Alexiades A. D. Solomon

(Abstract of *J. Non-Equilibrium Thermodynamics* (in press))

Continuing the work of Part I, the free energy of the solid-interface-liquid system is found as a function of the nucleus radius. Consistent with the development in Part I, interfacial area, curvature, and pressure effects are taken into account. Thus, we can determine which of the two possible

nucleus sizes will be more stable. To compare with classical theory, results parallel to those of Part I are developed based on classical nucleation theory and the classical Gibbs-Thomson relation. The predictions of the two theories are compared on the nucleation of supercooled water.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research; by Microgravity Science and Applications Division of NASA, Marshall Space Flight Center; and by Science Alliance, a State of Tennessee Center of Excellence through the University of Tennessee, Knoxville, TN.

1.5

THE FORMATION OF A SOLID NUCLEUS IN SUPERCOOLED LIQUID

V. Alexiades A. D. Solomon
D. G. Wilson

[Abstract of ORNL-6280, June 1986; also *J. Non-Equilibrium Thermodynamics* (in press)]

A careful analysis of the thermodynamics of a phase transition involving supercooled liquid is presented. Relations are developed for equilibrium temperature, pressures and volumes of solid and liquid from conservation relations and mathematical statements of thermal, mechanical and chemical equilibrium. Surface area, curvature and pressure effects are considered. Initial data are the temperature, pressure and volume of a supercooled liquid in which nucleation is assumed to have occurred. Generalized Clapeyron type equations in the presence of curved interfaces and a generalization of the Gibbs-Thompson relation between curvature of the phase change interface and the transition temperature at the interface are derived and discussed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and Microgravity Science and Applications Division of the National Aeronautics Space Administration.

1.6

SIMULATION OF AN ELECTROCHEMICAL PLATING PROCESS

J. Bullock* G. Giles†
L. J. Gray

[Abstract of Book Chapter in *Topics in Boundary Element Research*, Vol. IV, Industrial Applications, Prof. C. A. Brebbia, Ed., Springer-Verlag (in press)]

Although electrochemical plating is an important technique for the production of precision or exotic parts, the determination of the appropriate plating cell configuration for producing a particular part geometry is often an expensive and time consuming trial-and-error process. This chapter describes a computer algorithm based upon the Boundary Element Method (BEM) for simulating the plating of a three-dimensional part. The structure of the Boundary Element calculation is exploited to easily solve the Laplace Equation with nonlinear boundary conditions and to increase the speed of the computation in several other respects. A problem with the accuracy of the basic technique (at the intersection of potential and insulated surfaces) was identified and corrected. The calculated plating showed excellent agreement with the results of an experimental plating run.

Research sponsored by U.S. Department of Energy.

*Energy Division.

†Computing and Telecommunications Division.

1.7

A SOLUTION FOR THE VISCOELASTIC RESPONSE OF A BERNOULLI-EULER SHAFT

J. B. Drake

(Abstract of oral presentation given at the 1985 DOE Numerical Analysis Special Interest Group Meeting, Sandia National Laboratory, Albuquerque, NM, August 14-15, 1985)

An analytic solution is developed for the Bernoulli-Euler shaft equation with the assumption of a particular form for "creep compliance

function" describing the viscoelastic behavior. Asymptotic results are stated along with some numerical results. Finally, a numerical method of solving the problem using Laplace transforms is discussed.

Research sponsored by the Centrifuge Division, Oak Ridge Gaseous Diffusion Plant.

1.8

A STUDY OF THE OPTIMAL TRANSITION TEMPERATURE OF PCM WALLBOARD FOR SOLAR ENERGY STORAGE

J. B. Drake

(Abstract of ORNL/TM-10210, September 1987)

In this report, we consider the performance of wallboard impregnated with phase change material. An ideal setting is assumed and several measures of performance discussed. With a definition of optimal performance given, the performance with respect to variation of transition temperature is studied. Results are based on computer simulations of PCM wallboard with a standard stud wall construction.

We find the diurnal heat capacity to be overly sensitive to numerical errors for use in PCM applications. The other measures of performance, diurnal effectiveness, net collected to storage ratio, and absolute discharge flux, all indicate similar trends. It is shown that the optimal transition temperature of the PCM is strongly influenced by amount of solar flux absorbed by the PCM.

Research sponsored by U.S. DOE Solar Buildings Research and Development Program.

1.9

PCMSOL — SIMULATION CODE FOR A PASSIVE SOLAR STRUCTURE INCORPORATING PHASE CHANGE MATERIALS

**J. B. Drake G. A. Geist J. M. Martin^{*}
C. Serbin[†] A. D. Solomon J. J. Tomlinson^{*}
P. Grotzka[‡] P. McCormick[‡]
J. Price[§] S. Brown^{**}**

(Abstract of ORNL-6359, January 1987)

In order to study the optimum properties, utilization, and economics of phase change materials (PCM) in a direct gain passive solar structure a computer simulation, PCMSOL, has been developed. This program, modeling a one-room home, permits the incorporation of PCM's and/or other high-thermal mass materials in the walls. The theory and basic relations used in the code are given. Some sample runs are discussed. The program is validated by comparison with data from an experimental passive solar structure in Huntsville, Alabama.

Research sponsored by Thermal Energy Storage Program, U.S. DOE Office of Energy Research.

^{*}Engineering Technology Division.

[†]Computing and Telecommunications Division.

[‡]Lockheed Missiles and Space Co., Huntsville, AL.

^{**}Rico Engineering, Miami, FL.

1.10

DESIGN OF PCM ENHANCED PASSIVE SOLAR STRUCTURES

**J. B. Drake G. A. Geist
M. D. Morris A. D. Solomon
J. M. Martin^{*} J. J. Tomlinson^{*}**

(Abstract of ORNL-6281, March 1987)

A design methodology for a passive solar structure using phase change materials for thermal storage is presented. The discussion focuses on the use of PCM's, charged by direct illumination of the sun. The interaction and importance of design elements are presented. The effect of material properties on the performance of a solar

structure is studied using a computer simulation of the structure for a heating season. The computed results indicate the importance of the choice of the transition temperature. An analytic expression approximating the computed results shows the effect of variation of the density and latent heat on the performance of the PCM as a thermal storage medium in the solar structure.

Research sponsored by U.S. DOE Solar Buildings Research and Development Program.

* Engineering Technology Division.

1.11

A COMPARISON BETWEEN THE BOUNDARY ELEMENT AND FINITE ELEMENT METHODS FOR AN ELECTROCHEMICAL PLATING PROBLEM

G. Giles* L. J. Gray

(Abstract of paper presented at the Boundary Element Technology Conference, Massachusetts Institute of Technology, Cambridge, MA, June 17-19, 1986)

The goal of an electrochemical deposition operation is to produce a metal part with a specific shape, and numerical simulation can be used to economically design a plating cell which will manufacture this desired geometry. Since the design process will require many iterations with many different configurations of the cell, both speed and flexibility of the numerical method are important considerations. This paper presents a comparison of the boundary element and finite element methods when applied to the simulation of a plating system. The cell used for this study is of practical interest and is typical of the complicated three-dimensional geometries which can arise in deposition problems. It is concluded that the boundary element method is a more effective technique for use in plating simulations.

Research sponsored by the Y-12 Development Division and by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

* Computing and Telecommunications Division.

1.12

AC RESPONSE OF ROUGH SURFACES

L. J. Gray

(Abstract of a talk presented at the Gordon Research Conference on Solid State Ionics, Brewster Academy, Wolfeboro, NH, June 29 — July 3, 1986)

The small signal ac impedance of the interface between a blocking electrode and an electrolyte is known to be of the form $Z(\omega) = A(j\omega)^{-\alpha}$. This talk discusses the possible connection between this phenomenon and the fractal geometry of the interface.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.13

A PROGRAM FOR SOLVING THE 3-DIMENSIONAL LAPLACE EQUATION VIA THE BOUNDARY ELEMENT METHOD

L. J. Gray

(Abstract of ORNL/TM-9816, September 1986)

A subroutine for solving the interior three-dimensional Laplace equation $\nabla^2 V = 0$ by the boundary element method is described. The bounding surface is defined by triangular elements, each element defined by three nodes (vertices) in appropriate order for calculating the outward normal. The boundary data at a boundary node P is either the value of the potential $V(P)$ or the normal derivative $\frac{\partial V}{\partial \vec{n}}(P)$. The required integrals over the triangular elements are computed using linear interpolation from the nodal values. This routine has been especially tailored in several ways for use in modeling electrochemical processes.

Research sponsored by Y-12 Development Division.

1.14

BOUNDARY ELEMENT METHOD FOR HEAT TRANSFER BETWEEN CONTACTING NON-CONFORMING SURFACES

L. J. Gray G. E. Giles*

(Abstract of paper presented at the 9th International Boundary Element Conference, University of Stuttgart, Germany, August 31 - September 4, 1987)

Steady state heat transfer through a contact region between two surfaces is solved numerically by the boundary element method. Circular and highly elliptical contact regions of constant temperature are considered. Exploiting the symmetry of the problem, specialized Green's functions are employed, thereby reducing the computation time and considerably simplifying the task of constructing a very refined mesh near the contact edge. This type of discretization is required because of the singular behavior of the heat flux at the edge. Accurate fluxes for this difficult problem are obtained utilizing a new extrapolation technique for treating the edge discontinuity.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Computing and Telecommunications Division.

1.15

PROGRESS ON BOUNDARY ELEMENT TECHNIQUES FOR ELECTROPLATING SIMULATION

L. J. Gray G. E. Giles*
J. S. Bullock†

(Abstract of oral presentation presented at BETECH '87, Rio de Janeiro, Brazil, June 1987, also book chapter, C. A. Brebbia, Ed., Springer/Verlag (in press))

There are many advantages to using the Boundary Element Method for simulating an electrochemical plating process. However, previous work has indicated a problem with the accuracy of the computed current density at the intersection of a potential surface with a symmetry plane. It is demonstrated herein that accurate current densities can be easily obtained if a specialized Green's function (reflected singularities)

is employed. Use of this method produces much better agreement with the experimental plating results.

Numerical complications also arise when thin insulated shielding is present in the plating tank. (In many practical applications, a shield is used in order to modify the current density on the part.) The standard numerical treatments of such a narrow internal "hole" are either to decompose the region into several simply connected pieces by adding fictitious boundary surfaces, or to use a sufficiently thick shield, thereby avoiding the inherent numerical problems. These approaches are very inconvenient for electrochemical applications: additional nodes and elements can substantially increase computer time, whereas a finite thickness model of a perforated shield would be exceedingly cumbersome. A new Boundary Element technique for treating a zero thickness insulated shield has been developed; this method should be applicable to any problem with this type of geometry. As additional internal surfaces are not required, it is very efficient in regards to both computation and data preparation time. A three-dimensional example calculation for a realistic plating situation is presented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Computing and Telecommunications Division.

†Y-12 Development Division.

1.16

ANALYTIC CONTINUATION AND GREEN'S FUNCTION CALCULATIONS

L. J. Gray T. Kaplan*

(Abstract of ORNL-6191, November 1985; also *J. Phys. A: Math. Gen.* **19**, 1555 (1986))

Hass, Velicky, and Ehrenreich have shown that Green's function values can be obtained appreciably faster by performing the calculation at complex energies with large imaginary parts and then coming back to real energies by an analytic continuation algorithm. However, analytic continuation is numerically unstable and thus an error analysis is essential if one is to have confi-

dence in the results of the continuation. In this paper, error estimates are obtained for the power series method of Hass *et al.* and also for a method based upon Cauchy's Theorem introduced herein. These estimates can be used to select appropriate values for the parameters of the continuation algorithms and also to determine which of the two methods is most appropriate for a given calculation.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Solid State Division.

1.17

A COMMENT ON FRACTALS AND THE FREQUENCY DEPENDENT IMPEDANCE OF BLOCKING ELECTRODES

L. J. Gray T. Kaplan*
S. H. Liu*

[Abstract of *Electrochimica Acta* (in press)]

Nyikos and Pajkossy's general treatment of the effect of surface roughness on the impedance of blocking electrodes yields the relationship $\eta = (\bar{d}_f - 1)^{-1}$ between the fractal dimension of the interface and the frequency exponent of the impedance. In this note it is shown that their analysis is incorrect.

Research sponsored by Applied Mathematical Sciences Research Program and Division of Materials Sciences, U.S. DOE Office of Energy Research.

*Solid State Division.

1.18

THE FRACTAL DIMENSION OF A RANDOM MODEL FOR A ROUGH INTERFACE

L. J. Gray T. Kaplan*
S. H. Liu*

(Abstract of paper presented at the SIAM National Meeting, Boston, MA, July 21-25, 1986)

A random fractal based upon the Cantor Dust has been used as a model for a rough electrode-

electrolyte interface. The fractal dimension is shown to be given by an equation involving the probability distributions of the scaling and branching of the fractal. Under physically reasonable conditions this equation has a unique solution in the required range. The impedance of this interface is calculated and is related to the fractal dimension.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and the Division of Materials Sciences.

*Solid State Division.

1.19

EFFECT OF DISORDER ON A FRACTAL MODEL FOR THE AC RESPONSE OF A ROUGH INTERFACE

T. Kaplan* L. J. Gray

[Abstract of *Phys. Rev. B* 32(11), 7360 (1985)]

The effect of disorder on the fractal model of Liu for a rough interface between two materials of very different conductivities is examined. It is found that the average admittance has the experimentally observed property of a constant phase-angle (CPA) element. The exponent η of the frequency dependence of the CPA element depends on the specific form of the probability distribution of the scaling. Furthermore, the fractal dimension $\bar{d}_f$ of the random surface area of the interface is calculated, and $\eta = 3 - \bar{d}_f$.

Research sponsored by U.S. Department of Energy.

*Solid State Division.

1.20

**A PROJECT TO EXPERIMENTALLY
AND THEORETICALLY EXAMINE
FLUID INTERFACIAL WAVE
PHENOMENA IN A ROTATING
CYLINDRICAL GEOMETRY: CURRENT
RESULTS AND FUTURE PLANS**

W. F. Lawkins S. Thompson
W. K. Sartory* G. T. Gillies†
R. C. Ritter†

(Abstract of ORNL-6419, September 1987)

A prototype of the new instrument for experimentally studying stratified fluid wave phenomena in a rotating cylindrical geometry, both of infinitesimal and nonlinear forms, has been designed, built, and partially characterized. Furthermore, a model for analyzing the use of control forces to eliminate infinitesimal instabilities from the fluid/mechanical system has been developed and used. Finally, a nonlinear model for analyzing forced interfacial waves has been defined and steps are currently being taken to implement that model.

Research sponsored by U.S. Department of Energy.

*Engineering Technology Division.

†University of Virginia, Charlottesville, VA.

1.21

**A NUMERICAL STUDY OF THE
PERFORMANCE OF LATENT
HEAT STORAGE FOR SOLAR
DYNAMIC POWER SYSTEMS**

A. D. Solomon

(Abstract of ORNL-6218, January 1986; also paper presented at the Twentieth IECEC Meeting, Miami Beach, FL, August 19, 1985)

A conceptual design of a space station power system based on a Brayton cycle and solar powered has been developed. A key component of such a system is the thermal energy storage module, which is of crucial importance during periods of darkness. We have developed a computer program, FPAK1.F, simulating one possible

storage design. We describe the code and, using it, raise some questions about the system under study.

Research sponsored by the Division of Physical and Chemical Energy Storage Systems, U.S. DOE Office of Energy Research.

1.22

**AN ENTHALPY METHOD
FOR THE SOLIDIFICATION
OF A SUPERCOOLED LIQUID**

A. D. Solomon V. Alexiades
D. G. Wilson G. Geist
J. Kerper*

(Abstract of ORNL-6217, March 1986)

The classical enthalpy formulation of phase change processes does not permit modeling solidification of supercooled liquids. This report describes an enthalpy-based method for simulating a freezing process involving a planar front moving into a supercooled but not hypercooled liquid. The method is applicable when the liquid is initially below its equilibrium freezing temperature, T_σ , but above $T_\sigma - H/c_L$. Here H and c_L are the latent heat of solidification and the specific heat of the liquid respectively. The report also discusses a computer implementation of the method in one dimension and results of its application to a particular problem with an explicit solution.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Southern University, Birmingham, AL.

1.23

**A HYPERBOLIC STEFAN PROBLEM
WITH DISCONTINUOUS TEMPERATURE**

A. D. Solomon V. Alexiades
D. G. Wilson J. Greenberg*

(Abstract of ORNL-6216, March 1986)

In an earlier paper a Stefan problem for hyperbolic heat transfer was formulated under the condition of continuity of the temperature at

the moving front. In this paper we examine this assumption and present an alternative model in which continuity is not imposed. For this case, a problem with an explicit solution is presented, as are some qualitative properties of solutions to some similar problems. In addition, we derive quasi-steady approximate solutions to certain other benchmark problems.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Maryland, Baltimore, MD.

1.24

THE DEVELOPMENT OF A SIMULATION CODE FOR A LATENT HEAT THERMAL ENERGY STORAGE SYSTEM IN A SPACE STATION

A. D. Solomon M. D. Morris
J. Martin* M. Olszewski*

(Abstract of ORNL-6213, April 1986)

A conceptual design of a space station power system based on a Brayton cycle and solar powered has been developed. A key part of such a system is the thermal energy storage module, which is of crucial importance during periods of darkness. We have developed a simulation code for one possible storage configuration. In this report, we describe the considerations entering into the code development, and some results obtained thus far.

Research sponsored by Thermal Energy Storage Program, U.S. DOE Office of Energy Research.

*Engineering Technology Division.

1.25

A STEFAN-TYPE PROBLEM WITH VOID FORMATION AND ITS EXPLICIT SOLUTION

A. D. Solomon D. G. Wilson

[Abstract of ORNL-6277, June 1986; *IMA J. Appl. Math.* 37, 67 (1986)]

For most materials, the densities of the solid and liquid phases are different. For some materi-

als being considered as potential latent heat thermal energy storage materials, this density change is large. When the solid phase is more dense than the liquid, solidification may result in the formation of vapour bubbles or voids. We have formulated a problem, representing a phase change process with such a void, that has an explicit solution. We examine the solution to gain a further understanding of the thermal and phase change performance of a material in which such voids form. We use the solution to analyze an example problem involving freezing lithium fluoride, a candidate phase-change material with a density change on freezing of about 25 percent.

Research sponsored by Applied Mathematical Sciences Research Program and by Thermal Energy Storage Program, U.S. DOE Office of Energy Research.

1.26

AN APPROXIMATE ANALYSIS OF THE FORMATION OF A BUOYANT SOLID SPHERE IN A SUPERCOOLED MELT

A. D. Solomon D. G. Wilson
V. Alexiades

(Abstract of ORNL-6212, March 1986)

A mathematical model is presented for the idealized formation and development of a buoyant sphere solidifying in an infinite pool of supercooled liquid. The solid and liquid are of the same pure material and the solid is less dense than the liquid. Initially the liquid is at a uniform temperature that is below its equilibrium freezing temperature, T_σ , but above the so called hypercooled temperature, $T_\sigma - H/c_L$. Here H and c_L are the latent heat of solidification and the specific heat of the liquid respectively. An approximate solution is derived based on the Megerlin approximation method.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and by Microgravity Science and Applications Division of the National Aeronautics and Space Administration.

1.27

**AN APPROXIMATE SOLUTION
TO THE PROBLEM OF SOLIDIFICATION
OF A SPHERE OF SUPERCOOLED FLUID**

**A. D. Solomon D. G. Wilson
V. Alexiades**

(Abstract of ORNL-6292, August 1986)

Using a heat balance integral approach we find approximations to the temperature distribution and front location for the solidification of a supercooled spherical melt. The accuracy of these approximations is examined by comparison with the results of numerical computations and the exact solution to an approximating problem.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.28

**A COLLECTION OF TEST PROBLEMS
FOR ORDINARY DIFFERENTIAL
EQUATION SOLVERS WHICH HAVE
PROVISIONS FOR ROOTFINDING**

S. Thompson

(Abstract of ORNL/TM-9912, August 1987)

Several popular ordinary differential equation (ode) solvers contain provisions for locating roots of functions which depend on the solution of the ode. A collection of problems for testing such solvers is described in this report. In addition to several well known problems, the collection contains other interesting problems which have not previously appeared in the literature.

Research sponsored by Computing and Telecommunications Division.

1.29

**A QUANTITATIVE ASSESSMENT
OF THE EFFECT OF PARTIAL
PIVOTING IN SPARSE ORDINARY
DIFFERENTIAL EQUATION SOLVERS**

S. Thompson

[Abstract of ORNL-6207, May 1986; *Comp. Math. with Appl.* 12A(12), 1183 (1986)]

This report considers the effect of partial pivoting in automatic ordinary differential equation solvers which utilize sparse matrix techniques. Two solvers are considered, the well-known LSODES solver and a derivative LSOD28. LSODES uses the Yale Sparse Matrix Package which does not perform partial pivoting. LSOD28 uses the Harwell MA28 Sparse Matrix Package which does perform partial pivoting. Results are presented for a benchmark problem which contains several features typically present in realistic problems. The results demonstrate that both solvers perform satisfactorily. At the same time, they demonstrate the relative effects of partial pivoting for the benchmark problem. In particular, they suggest that partial pivoting substantially improves neither the efficiency nor the reliability of LSODES for such problems. They support the argument that partial pivoting is not necessarily required in adaptive solvers to solve complex problems accurately and efficiently.

Research sponsored by Computing and Telecommunications Division.

1.30

**IMPLEMENTATION AND EVALUATION
OF SEVERAL CONTINUOUSLY
IMBEDDED METHODS OF SARAFYAN**

S. Thompson

[Abstract of ORNL/TM-10434, August 1987; also *J. Appl. Num. Anal.* (in press)]

Several of Sarafyan's continuously imbedded methods have been implemented and evaluated. This study discusses several important implementation questions and presents results that demon-

strate the effectiveness of the resulting software. The results indicate that Sarafyan's methods are well suited for the solution of ordinary differential equations requiring rootfinding to handle special events and interpolation for dense output. The results further indicate that the software based on several of the higher order methods is competitive with other widely used general purpose Runge-Kutta software.

Research sponsored by Computing and Telecommunications Division.

1.31

NUMERICAL EXPERIMENTS WITH PIVOTING IN SPARSE ODE SOLVERS

S. Thompson

(Abstract of oral presentation given at the 1985 DOE Numerical Analysis Special Interest Group Meeting, Sandia National Laboratory, Albuquerque, NM, August 14-15, 1985)

In this talk we discuss the effect of partial pivoting in automatic ordinary differential equation solvers which utilize sparse matrix techniques. Two solvers are considered, the well known LSODES solver and a derivative LSOD28. LSODES uses the Yale Sparse Matrix Package which does not perform partial pivoting. LSOD28 uses the Harwell MA28 Sparse Matrix Package which does perform partial pivoting. Results are presented for a benchmark problem which contains several features typically present in fluid flow problems. The results demonstrate that both solvers perform satisfactorily. At the same time, they demonstrate the relative effects of partial pivoting for the benchmark problem. In particular, they suggest that partial pivoting substantially improves neither the efficiency nor the reliability of LSODES for such problems. They support the argument that partial pivoting is not necessarily required in adaptive solvers to solve fluid flow problems accurately and efficiently.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.32

ON THE USE OF CORLIB SUBROUTINES FOR THE SOLUTION OF A MODEL FLUID FLOW PROBLEM

S. Thompson

(Abstract of ORNL/TM-10038, December 1986)

This report describes the use of several subroutines from the CORLIB core mathematical subroutine library for the solution of a model fluid flow problem. The model consists of the Euler partial differential equations. The equations are spatially discretized using the method of pseudo-characteristics. The resulting system of ordinary differential equations is then integrated using the method of lines. The stiff ordinary differential equation solver LSODE from CORLIB is used to perform the time integration. The non-stiff solver ODE is used to perform a related integration. The linear equation solver subroutines DECOMP and SOLVE are used to solve linear systems whose solutions are required in the calculation of the time derivatives. The monotone cubic spline interpolation subroutines PCHIM and PCHFE are used to approximate water properties. The report describes the use of each of these subroutines in detail. It illustrates the manner in which modules from a standard mathematical software library such as CORLIB can be used as building blocks in the solution of complex problems of practical interest.

Research sponsored by Computing and Telecommunications Division.

1.33

REMARKS ON THE CHOICE OF A STIFF ORDINARY DIFFERENTIAL EQUATION SOLVER FOR THE SOLUTION OF FLUID FLOW PROBLEMS

S. Thompson

[Abstract of ORNL-6189, March 1986; also *Comp. Math. with Appls.* 12A(11), 1125 (1986)]

This report discusses several aspects of the solution of fluid flow problems. A model problem

is described which captures several of the salient characteristics of such problems. The model problem is derived from the one-dimensional Euler equations. It corresponds to the subcooled liquid region of a three region reactor steam generator model. The defining partial differential equations are discretized spatially using the method of pseudo-characteristics. The resulting system of ordinary differential equations is then solved by the method of lines using each of several available ordinary differential equation (ode) solvers. In addition to demonstrating that fluid flow problems can be solved effectively using adaptive mathematical software, the results also illustrate the typical performance of each solver as well as the relative merits of special solver features (e.g., automatic method switching and exploitation of problem sparsity or bandedness). The model problem is also modified and used to illustrate several commonly observed characteristics of fluid flow models. The results illustrate the potential effect on solver performance of characteristics such as inaccurate water property calculations. Consequently, they explain apparent anomalies often attributed incorrectly to poor solver design and algorithmic implementation. The results also support the choice of the sparse ordinary differential solver LSODES for the solution of fluid flow problems.

Research sponsored by Computing and Telecommunications Division.

1.34

SOFTWARE FOR ROOTFINDING AND INTERPOLATION WITH RUNGE-KUTTA-SARAFYAN METHODS

S. Thompson

[Abstract of ORNL-6151, September 1985; also *Trans. Soc. Comp. Simu.* 2(3), 207 (1985)]

Mathematical software is described which implements Runge-Kutta methods of Sarafyan. Due to the embedded nature of the methods, it is possible to perform both rootfinding and interpolation in a very natural manner. The software described contains provisions for both rootfinding and interpolation. The ability to do rootfinding

makes it possible to efficiently handle discontinuities and special events as well as other rootfinding tasks. The ability to do interpolation without negatively impacting the integration stepsize selection process makes it possible to handle the question of dense output in an efficient manner. Examples are presented to illustrate the types of problems which may be solved and to demonstrate the typical performance of the software.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.35

STABILITY OF SOME CONTINUOUSLY IMBEDDED RUNGE-KUTTA METHODS OF SARAFYAN

S. Thompson

[Abstract of *Comput. Math. Appli.* 13(8), 677 (1987)]

Sarafyan and others have recently developed novel explicit Runge-Kutta methods. Associated with each method is an imbedded polynomial which interpolates the Runge-Kutta method and which is itself a Runge-Kutta approximation at non-mesh points. In this paper, we show that the interpolation polynomials possess the desirable stability properties of the Runge-Kutta methods.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.36

ITERATIVE SOLUTION OF A NONLINEAR SYSTEM ARISING IN PHASE CHANGE PROBLEMS

M. A. Williams*

(Abstract of ORNL-6398, August 1987)

We consider several iterative methods for solving the nonlinear system arising from an enthalpy formulation of a phase change problem. We present the formulation of the problem. Implicit discretization of the governing equations results in a mildly nonlinear system at each time step. We discuss solving this system using

Jacobi, Gauss-Seidel, and SOR iterations and a new modified preconditioned conjugate gradient (MPCG) algorithm. The new MPCG algorithm and its properties are discussed in detail. Numerical results are presented comparing the performance of the SOR algorithm and the MPCG algorithm with 1-step SSOR preconditioning. The MPCG algorithm exhibits a super-linear rate of convergence. The SOR algorithm exhibits a linear rate of convergence. Thus, the MPCG algorithm requires fewer iterations to converge than the SOR algorithm. However in most cases, the SOR algorithm requires less total computation time than the MPCG algorithm. Hence, the SOR algorithm appears to be more appropriate for the class of problems considered.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and Oak Ridge Associated Universities.

* Lehigh University, Bethlehem, PA.

1.37

IMPSOR, A FULLY VECTORIZED FORTRAN CODE FOR THREE- DIMENSIONAL MOVING BOUNDARY PROBLEMS WITH DIRICHLET OR NEUMANN BOUNDARY CONDITIONS

M. A. Williams* D. G. Wilson

(Abstract of ORNL-6393, August 1987)

This report documents IMPSOR, a FORTRAN code that implements finite difference methods for multidimensional moving boundary problems with Dirichlet or Neumann boundary conditions on a Cray X-MP. The geometry of the spatial domain is a rectangular parallelepiped. The dimensions of the parallelepiped are specified by the user. Dirichlet or Neumann boundary conditions may be specified on each face of the box independently. The initial conditions are arbitrary. The user defines the initial and boundary conditions as well as the thermal and physical properties of the problem. Additionally, several parameters of the numerical method, e.g. degree of implicitness, time step size, are also specified by the user.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and Oak Ridge Associated Universities.

* Lehigh University, Bethlehem, PA.

1.38

VECTORIZED DIFFERENCE SCHEMES FOR A THREE-DIMENSIONAL ENTHALPY FORMULATION FOR PHASE CHANGE PROBLEMS

M. A. Williams* D. G. Wilson

(Abstract of ORNL/TM-10034, July 1986)

Fully vectorized codes have been written for the Cray X-MP implementing explicit and implicit finite difference schemes for enthalpy formulations of three-dimensional Stefan-like problems. The implicit scheme is that proposed by C. M. Elliot and J. R. Ockendon. The explicit scheme is intended to provide a comparison for the results from the implicit scheme. Vectorization of the code required some ingenuity since material properties change discontinuously as solidification proceeds. Boolean variables were used to avoid conditional branches in DO loops. Average vector length was greatly increased by unfolding three-dimensional arrays and treating them as long vectors. This report documents the development of the code and the vectorization strategies. The investigation of the tradeoffs between the implicit scheme, potentially capable of taking large time steps, and the explicit scheme, whose time step size is limited by the stability criterion, has begun but is not complete.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

* Lehigh University, Bethlehem, PA.

1.39

APPLIED ANALYSIS RESEARCH, CONSULTING AND COLLABORATION AT ORNL

D. G. Wilson

(Abstract of oral presentation to be given at a Mathematics Department Seminar, Northern Illinois University, DeKalb, IL, October 9, 1987)

We summarize research, consulting and collaboration activities of the mathematics research group of the Mathematical Sciences Section of the Engineering Physics and Mathematics Division of the Oak Ridge National Laboratory. The presentation includes brief descriptions of Moving

Boundary Problems Research and consulting work with the Environmental Sciences Division (on modeling bacterial growth and degradation of organic contaminants in an aquifer) and with Engineering Technology (on a computer model of a thermal energy storage system for the proposed space station).

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.40

COMPUTER MODELING OF SOLIDIFICATION OF COMPOSITE MATERIALS

D. G. Wilson

(Abstract of oral presentation given at a seminar at the University of California, Santa Barbara, CA, November 4-5, 1985; also oral presentation entitled "Mathematical Modeling of Solidification Processes," given at the Lehigh University Mathematical Colloquium, Lehigh University, Bethlehem, PA, December 13, 1985, with A. D. Solomon and V. Alexiades)

An introduction to the mathematical and numerical modeling of solidification processes in composite materials is presented. First, a brief discussion of the mathematical modeling of phase change processes in pure materials is given. After a brief digression on phase diagrams, the classical (Rubinstein) model of binary alloy solidification is discussed. Then the enthalpy is introduced and its use in modeling phase change processes is presented. Finally a more comprehensive, enthalpy-based model of the solidification problem for composite materials is given. This model is formulated as a pair of conservation laws for mass and energy that hold over the entire domain of the problem. A finite difference scheme for obtaining an approximate solution of the model equations is discussed and numerical results are presented. With this model, it is not necessary to explicitly track the solid/liquid interface, and the "interface" may develop into a mushy region.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.41

MATHEMATICAL MODELING OF SOLIDIFICATION OF BINARY ALLOYS

D. G. Wilson

(Abstract of a talk presented at Ege University, Ismir, Turkey, June 24, 1986; at Andolu University, Eskisehir, Turkey, July 3, 1986; and at Middle East Technical University, Ankara, Turkey, July 7, 1986)

An introduction to the mathematical and numerical modeling of binary alloy solidification is presented. First, a brief discussion of the mathematical modeling of phase change processes in pure materials is given. After a short digression on phase diagrams, the classical (Rubinstein) model of binary alloy solidification is discussed. Then the enthalpy is introduced and its use in modeling phase change processes is presented. Finally a more comprehensive, enthalpy-based model of the solidification of a mixture or binary alloy is given. This model is formulated as a pair of conservation laws for mass and energy that hold over the entire domain of the problem. A finite difference scheme for obtaining an approximate solution of the model equations is discussed. With this model it is not necessary to explicitly track the solid/liquid interface, and the "interface" may develop into a mushy region.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.42

MATHEMATICAL MODELING OF SOLIDIFICATION PROCESSES

D. G. Wilson

(Abstract of a talk presented at Dokuz Eylül University, Ismir, Turkey, June 23, 1986 and at Andolu University, Eskisehir, Turkey, July 3, 1986)

A survey is presented of the mathematical models and methods used to study various solidification processes in the Moving Boundary Problems Research Project at the Oak Ridge National Laboratory. The processes under study

include Stefan-like problems, binary alloy solidification, and ultrarapid melting and resolidification associated with laser annealing. The mathematical models involve conservation laws for energy and mass. Both analytic and numerical approximations schemes have been developed. The computational models involve a discrete, weak formulation of the corresponding mathematical equations that does not require explicitly tracking the solidification front. Explicit finite difference schemes are usually used to approximate the partial differential equations, but recently some calculations have been done with an implicit scheme.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.43

NUMERICAL METHODS FOR MODELING SOLIDIFICATION OF COMPOSITE MATERIALS

D. G. Wilson

(Abstract of oral presentation given at a seminar at the University of California, Santa Barbara, CA, November 4-5, 1985)

In this talk a more detailed discussion of the numerical aspects of the computer modeling of solidification processes in composite materials is presented. The finite difference equations and the method of solving them is discussed. Possible extensions and alternatives will also be presented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.44

PHASE CHANGE PROBLEMS GOVERNED BY PARTIAL DIFFERENTIAL EQUATIONS OF NON-PARABOLIC TYPE

D. G. Wilson

(Abstract of oral presentation presented at the Free Boundary Problems: Theory and Applications International Colloquium, Irsee, Bavaria, West Germany, June 11-20, 1987)

A well-known shortcoming of the classical formulation of mathematical models for heat transfer processes, including phase change problems, in terms of parabolic partial differential equations is the models' incorrect treatment of ultrarapid heat transfer (that occurs, for example, in laser annealing). Researchers at ORNL have begun a study of mathematical models for phase change problems based on alternate heat transfer equations that avoid this shortcoming. The study of such models, based on hyperbolic partial differential equations or delay equations, is based in an embryonic state. In this talk we characterize these alternate formulations and present some preliminary results from their analysis.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

Statistics

1.45

**INTEGRATED AND INDIVIDUAL
BIOCHEMICAL RESPONSES OF
RAINBOW TROUT (*SALMO
GAIRDNERI*) TO VARYING
DURATIONS OF ACIDIFICATION
STRESS**

**S. M. Adams^{*} C. A. Burtis[†]
J. J. Beauchamp**

[Abstract of *Comp. Biochem. Physiol.* 82C(2), 301 (1985)]

Rainbow trout displayed a variety of biochemical responses when exposed to pH 4.5 for periods of 6–48 hr. Some adaptive or recovery responses occur in rainbow trout after 12–24 hr of continuous exposure to reduced pH, with most biochemical variables returning to near control levels following 48 hr of nonexposure. The integrated biochemical response of trout to acidification stress was determined by incorporating all 10 measured biochemical variables into a discriminant analysis procedure. Measures of electrolyte homeostasis (sodium), carbohydrate metabolism (glucose), lipid metabolism (triglyceride) and amino acid metabolism (serum glutamate oxaloacetate transaminase) provide the best indicators of individual biochemical responses of trout to reduced pH. Determination and interpretation of fish response to reduced pH can differ, depending on whether individual or multiple biochemical variables are being evaluated.

Research sponsored by U.S. Department of Energy.

^{*}Environmental Sciences Division.

[†]Chemical Technology Division.

1.46

**TRANSFORMATION CONSIDERATIONS
IN DISCRIMINANT ANALYSIS**

J. J. Beauchamp D. S. Robson^{*}

[Abstract of *Commun. Statist.-Simula.* 15(1), 147 (1986)]

The linear discriminant function (LDF) is known to be optimal in the sense of achieving an

optimal error rate when sampling from multivariate normal populations with equal covariance matrices. Use of the LDF in nonnormal situations is known to lead to some strange results. This paper will focus on an evaluation of misclassification probabilities when the power transformation could have been used to achieve at least approximate normality and equal covariance matrices in the sampled populations for the distribution of the observed random variables. Attention is restricted to the two-population case with bivariate distributions.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

^{*}Biometrics Unit, Cornell University, Ithaca, NY.

1.47

**THE MATHEMATICAL SCIENCES SECTION
OF THE ENGINEERING PHYSICS AND
MATHEMATICS DIVISION OF OAK RIDGE
NATIONAL LABORATORY**

J. J. Beauchamp A. D. Solomon

(Abstract of paper presented at Martin Marietta Corporation, Baltimore, MD, September 4, 1985)

The Mathematical Sciences section had its beginnings in the Mathematics Panel organized by Professor Alston S. Householder for the Oak Ridge National Laboratory (ORNL) in 1948. Dr. Householder attracted a number of mathematicians and statisticians to his staff, and by 1956 he had formed mathematics and statistics sections, which together with an expanding group of computer scientists became the Mathematics Division of the Laboratory in 1962. Dr. Householder led the Mathematics Division until he retired in 1969. Dr. Harvey P. Carter then became Director of the Mathematics Division and in 1973 organized the Computer Sciences Division, responsible for a broad spectrum of duties ranging from fundamental research in the Mathematical Sciences to the maintenance of the extensive computer network at the Oak Ridge DOE installation. The research arm of the Division was located in the Mathematics and Statis-

tics Research Department of the Computer Science Division until February 1984, when it became a section of a new Engineering Physics and Mathematics Division of Oak Ridge National Laboratory headed by Dr. Fred Maienschein. The current head of the Mathematical Sciences Section is Dr. Robert Ward.

The Mathematical Sciences section has three main aims:

1. To perform mathematical, statistical, and computer science research which is germane to the solution of the nation's energy problems;
2. To consult and collaborate with other scientists working on these problems, and
3. To provide for technical development and growth of its personnel in advanced and cutting-edge mathematical, statistical, and computer science technology.

In support of its computational and research needs the section has access to a number of large, high-speed computers. In addition it houses a Research Computing Facility consisting of a VAX 11/780 and an Intel Hypercube parallel processor. The VAX computer serves in-house computing and communications needs, and as a link to the ARPANET for which it is ORNL node. The Hypercube is a state-of-the-art asynchronous parallel processor which is serving as a research tool in the effort to explore computational algorithms for parallel computers. To meet its substantive computing needs the section has network access to CRAY and CYBER computers as well.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.48

APPROXIMATIONS TO THE DISTRIBUTIONS — THE PRACTICAL EXAMPLES

K. O. Bowman

(Abstract of oral presentation given on behalf of the COPSS Lecture Program at the Southern College, Collegedale, TN, February 27, 1986)

In this talk, the historical aspect of the developments of the study of approximations to the distributions (Pearson system, Johnson translation system) are discussed along with application of the method to the problem of weather modification. The experiment was carried out at Bowen Power Plant in south Georgia by ORNL scientists to determine whether the thermal effect of the plant makes any significant difference to the pattern of weather (rainfall). We successfully showed by using sample skewness and kurtosis that it does not affect the amounts of rainfalls, but the pattern of rainfall is significantly different from that of control areas.

Research sponsored by U.S. Department of Energy.

1.49

NEW DIRECTIONS FOR WOMEN, MINORITIES, AND DISABLED: REPORT FROM THE NATIONAL SCIENCE FOUNDATION COMMITTEE ON EQUAL OPPORTUNITIES IN SCIENCE AND TECHNOLOGY

K. O. Bowman

(Abstract of a talk presented at the Association for Women in Science Local Chapter Meeting, Oak Ridge, TN, May 19, 1986)

According to the new master report by the Scientific Manpower Commission, the salary gains have been modest over the past two years for scientists and engineers, barely keeping abreast of inflation. However, women continue to earn substantially less than their male colleagues working in R&D, regardless of field or degree level. The Congress established the Committee of

Equal Opportunity in Science and Technology by enacting Public Law 96-516, the National Science Foundation FY 1981 Authorization Act, and the Science and Technology Equal Opportunities Act.

The law requires the Committee to report to the Congress every two years, and the members of the Committee just completed their third report. In this talk, the accomplishments of the Committee are reported.

Research sponsored by U.S. Department of Energy.

1.50

SMALL SAMPLE PROPERTIES OF STATISTICS — COMPUTER ALGORITHMIC APPROACH

K. O. Bowman

(Abstract of Thesis for Doctor or Engineering Degree, University of Tokyo, Tokyo, Japan (1986))

My thesis spans a period of study initiated in 1962 and continuing to the present. Although the thrust at first was directed towards the problem of efficiency of estimation as far as this was contained in first order variances, it gradually changed to broader aspects of this problem and was further modified by the advent of digital computers. Since progress in setting up further terms in ml moments seemed impossible, our study turned to moment estimators — perhaps there is an advantage in knowing more about less efficient estimators than less about more efficient estimators. The crux of the problem now turned to the evaluation of moments of products of sample moments, and since digital computers were coming into vogue, this new direction was exploited. Computer oriented extended Taylor series (COETS) were set up using a recursive algorithm; under the expectation operation these turned out to be divergent (based on the limited set of terms computed) but summation techniques proved powerful enough in general to produce acceptable assessments. Four moment approximating distributions were used in the final stages to provide approximate percentage points (or confidence intervals). Several hundred case studies are documented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.51

SMALL SAMPLE PROPERTIES OF STATISTICS — COMPUTER ALGORITHMIC APPROACH

K. O. Bowman

(Abstract of a talk presented at the Southern Regional Education Board/Southern Regional Committee on Statistics Summer Research Conference, Gatlinburg, TN, June 14-19, 1987)

In this talk, the historical aspects of the developments of the study of small sample properties of the statistics are discussed along with applications of the method to practical situations. The classical ideas are implemented by numerical methods on computer, with regard to sample sizes. The method "Computer Oriented Extended Taylor Series" (COETS) has been used to study statistics such as standard deviation, skewness statistics, kurtosis statistics, and parameter estimation, sampling from non-normal distributions. Surprisingly, most of the series expansions show divergent tendencies, and to assess the true values we must utilize the summation techniques. Validation of results has been studied by comparisons from alternatives summation devices, as well as simulation studies.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.52

SPECIAL CONCERNS: RESEARCH STATISTICS

K. O. Bowman

(Abstract of oral presentation given at the Research Meeting on Science and Mathematics for Students with Disabilities, Office of Opportunities in Science Linkage Project, Washington, DC, February 11, 1986)

The recent publications "Demographic Trends and the Scientific and Engineering Force," Office of Technology Assessment, and "Women and Minorities in Science and Engineering," National Science Foundation, state the difficulties in collecting the demographic data of physically disabled scientists. We itemize the problems of collecting such data and consider the direction to take from statistical points of view.

Research sponsored by U.S. Department of Energy.

1.53

STATISTICAL INFERENCE — COMPUTER ALGORITHMIC APPROACH WITH PRACTICAL EXAMPLES

K. O. Bowman

(Abstract of oral presentation presented at the University of Tennessee, Knoxville, TN, January 15, 1987)

In this talk, the historical aspects of the developments of the study of the small sample properties of the statistics are discussed along with application of the method to practical situations. The classical ideas are implemented by numerical methods on computer with regard to sample sizes. The tutorial example is given with the problem of estimating the parameters of gamma distribution.

Research sponsored by U.S. Department of Energy.

1.54

TOTAL QUALITY CONTROL AT THE KANSAI ELECTRIC POWER COMPANY

K. O. Bowman

[Abstract of *ONR Scientific Bulletin* 10(3) (1985)]

This article presents a TQC (total quality control) method used by Kansai Electric Power Company in Japan to win a prestigious Deming award in 1984 for their construction and operation of nuclear power plants.

Research sponsored by U.S. DOE Office of Naval Research.

1.55

THE LABORATORY FOR GASTROENTEROLOGY AT GUMMA UNIVERSITY

K. O. Bowman

[Abstract of *Scientific Bulletin* 10(1), 111 (1985)]

The Laboratory for Gastroenterology is a unit of the Medical Center at Gumma National

University in Maebashi, Japan. Directed by Professor Zen Itoh, it is well known for its work in gastrointestinal motor activity. When Itoh established the laboratory in 1970, a main technique was the measurement of gastrointestinal motor activity by strain gage transducers implanted in the serosal surface. Such implantations may have a long useful life, and they offer convenient recording, display, and computerized analysis of data.

Research sponsored by U.S. Department of Energy.

1.56

SERIES FOR STUDENT'S NON-CENTRAL t UNDER EXPONENTIAL SAMPLING WITH COMMENTS DUE TO H. P. MULHOLLAND

K. O. Bowman H. K. Lam*
L. R. Shenton*

[Abstract of *Commun. Statist.-Simula.* 15(3), 697 (1986)]

The moments of student's non-central t are only known in exact form for samples of $n=2, 3$, and 4, under exponential sampling. The exact distribution for $n \geq 5$ is unknown. Mulholland produced an exact recursive formula for the density of m'_2/m'_1^2 , and asserted that it consisted of $n-1$ splines on $(1, n)$. A computer oriented extended series (COETS) is taken out to terms in n^{-24} and appears to be strongly divergent. Several different approximation processes are used to study error analysis, including Levin's t -algorithm and simulations. Satisfactory assessments are indicated for all sample sizes exceeding about 25. The study involves a statistical problem, uses summation techniques in numerical methods and is for the most part highly computer oriented; considerable number crunching is unavoidable.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.57

STUDIES OF RANDOM NUMBER GENERATORS FOR PARALLEL PROCESSING

K. O. Bowman M. T. Robinson*

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 445 (1987)]

If Monte Carlo calculations are to be performed in a parallel processing environment, a method of generating appropriate sequences of pseudorandom numbers for each process must be available. Frederickson *et al.* proposed an elegant algorithm based on their concept of pseudorandom or Lehmer trees: the sequence of numbers from a linear congruential generator is divided into disjoint subsequences by the members of an auxiliary sequence. One subsequence can be assigned to each process. Extensive tests show the algorithm to suffer from correlations between the parallel subsequences: this is a result of the small number of bits which participate in the auxiliary sequence and illustrates the well-known discovery of Marsaglia. Two alternative algorithms are proposed, both of which appear to be free of interprocess correlations. One relaxes the conditions on the Lehmer tree by using an arbitrary auxiliary multiplier; it is not known to what extent the subsequences are disjoint. The other partitions the main sequence into disjoint subsequences by sending one member to each process in turn, minimizing interprocess communication by defining new sequence generating parameters.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and Division of Material Sciences.

*Solid State Division.

1.58

POWER TRANSFORMATION OF THE SAMPLE KURTOSIS

K. O. Bowman L. R. Shenton*

(Abstract of paper presented at the 46th Session of the International Statistical Institute, Tokyo, Japan, September 7-16, 1987)

The distribution of the sample kurtosis from general populations are considered. In most cases, its distribution is far from normal especially small samples. Power transformation turn out to be effective in reducing its skewness to near zero and its kurtosis close to the normal value three. Four moments approximating distributions are used to approximate percentage points. Applications to simulation studies should reduce the cycle size significantly for simulation stability.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.59

A REINFORCEMENT-DEPLETION URN MODEL: A CONTIGUITY CASE

K. O. Bowman L. R. Shenton*

[Abstract of *Stat. Theory Meth.* (in press)]

An urn contains balls of two colors. At a cycle there is a reinforcement of balls followed by a random depletion. After a number of cycles, what is the distribution of the two colors? The input of balls can be stochastic. The simplest case leads to hypergeometric distributions, usually after one cycle; multivariate hypergeometric functions also occur when many colors of balls are involved.

Are there any cases in which simple closed form solutions appear? This turns out to be the case when the depletion parameters subscribe to a certain structure. The product of a set of factorials has to have a property of contiguity. In this case hypergeometric-type solutions appear even when more than one cycle is involved.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.60

A SERIAL CORRELATION COEFFICIENT WHOSE MOMENTS SUFFER SURGES

K. O. Bowman L. R. Shenton*

(Abstract of oral presentation to be presented at the 1988 American Statistical Association Winter Conference, San Antonio, TX, January 6-8, 1988)

Shenton and Johnson considered the moments of serial correlation

$$\hat{\alpha} = \sum_{i=1}^n x_i x_{i-1} / \sum_{i=1}^{n-1} x_i^2,$$

$$(i=1,2,\dots,n)$$

where $x_i = \alpha x_{i-1} + \epsilon_i$, ($x_0 = 0$) is a discrete first-order auto-regressive scheme with the ϵ 's distributed as independent normal variates from $N(0,1)$, and $\hat{\alpha}$ the maximum likelihood estimator of α . A new solution for small samples were found and show periodic surges in the moment series arranged in powers of α . The method is implemented by computer oriented algorithm and higher moments of estimators can be computed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.61

STATISTICAL INFERENCE — COMPUTER ORIENTED ALGORITHMIC APPROACH

K. O. Bowman L. R. Shenton*

(Abstract of paper presented at the First International Association for Statistical Computing World Conference, Shizuoka, Japan, September 17-19, 1987)

Series for the moments of estimators and statistical functions often rely on a Taylor expansion, which is ultimately subject to modification by an expectation operator. These two phases are not of the same order of difficulty for, in general, it is the expectation of components of the series

which quickly defy analytical development. The evolution of the subject in recent decades has been significantly affected by numerical analysis which is computer oriented. General characteristics are hard to define and this paper illustrates the situations that can arise by briefly describing a few typical cases. Sign patterns and modulus patterns in components of series become discernible through extended computer methods and this aspect poses many new developments and unsolved problems.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.62

SUMS OF POWERS OF BINOMIAL COEFFICIENTS

K. O. Bowman L. R. Shenton*

[Abstract of *Communications in Statistics* (in press)]

An asymptotic series for sums of powers of binomial coefficients is derived, the general term being defined and usable with a computer symbolic language. Sums of squares of coefficients in the symmetric case are shown to have a link with classical moment problems, but this property breaks down for cubes and higher powers. Problems of remainders for the asymptotic series are mentioned. Using the reflection formula for $\Gamma(\cdot)$, a continuous form for a binomial function is set up, and this becomes oscillatory outside the usual range. A new continued fraction emerges for the logarithm of an adjusted sum of binomial squares. The note is a contribution to the problem of the interpretation of asymptotic series and processes for their conversion acceleration.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.63

THE DARK SIDE OF ASYMPTOTICS AND MOMENT SERIES

K. O. Bowman L. R. Shenton*

[Abstract of *Stat. Theory Meth.* (in press)]

Many moment series in the form of power series in n^{-1} (n the sample size) have proved to be so unusually complicated from a mathematical point of view that rarely are terms beyond n^{-2} found in closed acceptable form. This, in the first half of the century, doubtless focussed attention on low order asymptotic terms, with a reliance on subjective assessment of "large" in large sample theory. The advent of computerized analysis enabled the "delta" approach to be extended to terms of unimaginable complexity if pursued by pen and paper methods. It turns out that many series are divergent (or appear to be so from the finite set of terms made available). In some cases, for which an alternating sign pattern is established sooner or later, the approach to approximation using rational fractions in n turns out to be a powerful summatory algorithm. In recent years Padé methods and other convergence accelerating devices no longer need strong advocacy. The basic leap forward in this problem area is due mainly to Stieltjes, who proved that certain rational fraction approximating sequences to power series (convergent or divergent) actually converged over a large domain to a regular function, asymptotically related to the series. Whereas other accelerating devices are known (the Levin transient algorithm has proved useful) Padé usually proves to be an effective divergency dilutant.

The paper mentions series for the mean value of the standard deviation and moments of the sample skewness in non-normal sampling. A Stieltjes continued fraction for $1 - E(\sqrt{m_2})$ in exponential sampling turns out to be a useful summatory device. Another example concerns the moments of a statistic relating to a parameter of a Poisson distribution. Here nuisance terms appear (by direct mathematical approaches) and these are not picked up by the Taylor series algo-

rithm; in addition, divergent series in which all coefficients are one-signed appear, a rather unusual phenomenon. If it turns out that series for biases and covariances (including maximum likelihood estimator moments), when extended to terms of order n^{-24} or so, appear to diverge, then it would seem we must ask more searching questions about the information (not necessarily in the Fisher sense) contained and hidden in divergent series. In other words, what properties can be looked for when samples are finite; by far the most common occurrence in practice.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.64

THE TWO COLOR URN MODEL: RECURSIONS FOR THE MOMENTS

K. O. Bowman L. R. Shenton*

[Abstract of *Commun. Statist.-Simula.* 15(3), 787 (1986)]

For the two color reinforcement-depletion urn model with balancing reinforcement and depletion held constant over cycles, a recursive formula is given from which all factorial moments (for white balls, for example) can be determined.

The stationary distribution of white balls (infinite number of cycles) when the reinforcement of each color is positive, turns out to be determined by three parameters, namely (1) the total number of balls in the urn, (2) the richness of the reinforcement or ratio of white ball reinforcement to total reinforcement, and (3) the size of the white ball reinforcement. In addition, the distribution mimics the binomial [with less variance and skewness ($\sqrt{\beta_1}$)] and from formulas for the exact first four moments rapidly approaches normality. An approximating Gram-Charlier distribution with binomial nucleus, from a few cases studied, is only moderately successful.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.65

SIMULATION AND ESTIMATION PROBLEMS ASSOCIATED WITH THE 3-PARAMETER GAMMA DENSITY

K. O. Bowman^{*} L. R. Shenton^{*}
H. K. Lam^{*}

[Abstract of *Communications in Statistics* (in press); also paper presented at the American Statistical Association 1987 Joint Statistical Meetings, San Francisco, CA, August 17-20, 1987]

A new algorithm is introduced for the solution of the three parameter model, in which $\hat{s}$, $\hat{a}$, $\hat{\rho}$ refer to the maximum likelihood estimators of the threshold, scale, and shape parameters, respectively. This basically pivots on an equation for the threshold estimator, in the form $\hat{s} = \bar{x} - h(\hat{s}, x)$ the initial seed being $[x_{\min}]$. The other two equations are efficiently solved by another new quick algorithm for solving $\hat{\rho} = g^{-1}(y)$, where $\ln(\hat{\rho}) - \Psi(\hat{\rho}) = y$. It seems possible that in finite samples moments of $\hat{\rho}$ and $\hat{s}$ do not exist and indeed there is some doubt about the definition of asymptotic moments. However the statistic $\ln(\hat{\rho}) - \Psi(\hat{\rho})$ is less chaotic, and has low order moments not far removed from the normal and in some cases approximately χ^2 -type. For the maximum likelihood estimators we only consider cases for which $\rho > 2$. When $\rho \leq 2$, modified maximum likelihood estimators introduced by Cohen and Whitten are discussed. Four moments for each of the three estimators are simulated and from these non-extreme percentage points assessed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

^{*}University of Georgia, Athens, GA.

1.66

BRAIN CANCER AND NONOCCUPATIONAL RISK FACTORS: A CASE-CONTROL STUDY AMONG WORKERS AT TWO NUCLEAR FACILITIES

A. V. Carpenter^{*} W. D. Flanders[†]
E. L. Frome^{*} P. Cole[†]
S. A. Fry^{*}

[Abstract of *Am. J. of Public Health* (in press)]

In a nested case-control study of nuclear workers, 82 brain cancer cases were compared with 328 matched controls to investigate the possible association with nonoccupational risk factors such as histories of epilepsy or head injury. We observed a moderately strong association between brain cancer occurrence and history of epilepsy (OR=5.7, 95% CI=1.0-32.1), but did not find an association with previous head injury (OR=0.9, 95% CI=0.2-4.2).

Research sponsored by Oak Ridge Associated Universities, Oak Ridge, TN.

^{*}Oak Ridge Associated Universities, Oak Ridge, TN.

[†]University of Alabama at Birmingham, Birmingham, AL.

1.67

CENTRAL NERVOUS SYSTEM CANCERS AND RADIATION EXPOSURE: A CASE-CONTROL STUDY AMONG WORKERS AT TWO NUCLEAR FACILITIES

A. V. Carpenter^{*} W. D. Flanders[†]
E. L. Frome^{*} D. J. Crawford Brown[†]
S. A. Fry^{*}

[Abstract of *J. Occupational Medicine* (in press)]

A nested case-control study was conducted among workers employed in two nuclear facilities to investigate the possible association of primary CNS cancers with occupational exposure to radiation from external and internal sources. External radiation monitoring data were available for 27 cases and 90 matched controls from film badges for individual workers. The radiation doses to the lung from internally deposited

uranium were estimated for 47 cases and 120 matched controls from area and personnel monitoring data and were used in analyses in lieu of the brain doses. No association was observed between deaths from CNS cancers and exposure to ionizing radiation from external or internal sources. However, due to the small number of monitored subjects and low doses, a modest association could not be ruled out.

Research sponsored by Oak Ridge Associated Universities under contract with U.S. DOE Office of Energy Research.

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[†]University of Alabama at Birmingham, Birmingham, AL.

[‡]University of North Carolina, Chapel Hill, NC.

1.68

DETECTING SHIFTS IN RADIAL GROWTH RATES BY THE USE OF INTERVENTION DETECTION

D. J. Downing S. B. McLaughlin*

[Abstract of chapter in *Methods of Tree-Ring Analysis: Applications in the Environmental Sciences*, chapter title "Detecting Environmental Change From Tree Rings" (in press)]

In the study of several types of time series, including tree-ring chronologies, it is of interest to identify times of abrupt change in statistical characteristics of the series in order to make or test inferences about the mechanism(s) involved. The intervention detection technique may be used for that purpose. In this paper, we first describe the theoretical basis for the technique, which was developed from the Autoregressive Integrated Moving Average (ARIMA) methodology of Box and Jenkins. We then apply intervention detection to investigate the regional-scale variations in radial growth of red spruce (*Picea rubens*) over the last 20 years. Criteria were the magnitude and duration of negative step changes and the low frequency of positive changes within this time period signaling a unique combination of events. Differences in the timing and magnitude of changes between Northern and Southern stands are noted. These techniques are suggested to have good potential for detecting and contrasting

responses within and between other species and stands of forest trees.

Research sponsored by U.S. Environmental Protection Agency (EPA).

*Environmental Sciences Division.

1.69

STATISTICAL ANALYSIS OF CYTOGENETIC DOSE-RESPONSE CURVES

E. L. Frome

(Abstract of presentation given at the ASA Conference on Radiation and Health, Berkeley Springs, WV, July 20, 1986)

Regression methods are widely used in biomedical research to evaluate the effect of both quantitative and qualitative covariates on the response variable. In many situations of practical interest the dependent variable (y) is a count and the classical unweighted least squares procedure based on linear regression functions is not appropriate. An alternative approach is to use the Poisson distribution to describe the variation in the y 's, and more general nonlinear regression functions to describe the relation between the dependent variable and the covariates. Maximum likelihood estimates of the parameters can be obtained by means of iteratively weighted least squares. This general regression approach enables one to concentrate on describing the relation between the dependent variable and the covariates through the regression function. The deviance (which is minus two times the log-likelihood function) is used as a measure of residual (unexplained) variation. The results of fitting several different regression functions to the same data set can be summarized in an ANOVA-like table for Poisson regression models.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.70

USE OF POISSON REGRESSION MODELS IN STATISTICAL DATA ANALYSIS

E. L. Frome

(Abstract of paper presented at the 1987 American Statistical Association Winter Conference, Orlando, FL, January 8-9, 1987)

There are many situations in which the response y is a discrete variable that may follow the Poisson distribution. A regression function is specified that describes the relation between the expected value of y , a known covariate vector z , and an unknown vector of parameters. For general nonlinear regression functions, maximum likelihood (ML) estimates of the unknown parameters can be obtained using iterative reweighted least squares (IWLS). Consequently, statistical packages that support IWLS can be used to obtain ML estimates, their variances, and diagnostic measures that can be used to identify potential outliers and extreme points in the model space. A numerical example with a nonlinear dose-time-response model will be presented and limitations of statistical software will be discussed.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.71

STATISTICAL ANALYSIS OF CYTOGENETIC DOSE-RESPONSE CURVES

E. L. Frome

[Abstract of book chapter in *Statistical Methods in Toxicological Research*, Dr. D. Krewski and Dr. C. Franklin, Eds., Gordon & Breach Science Pubs., Inc. (in press)]

Dose-response curves are used in cytogenetic studies to provide a quantitative description of the relationship between chromosomal aberrations and dose of a mutagen. Estimates of the parameters can be obtained using iteratively weighted least squares (IWLS). When the dependent variable follows the Poisson distribution, the IWLS

algorithm is equivalent to using the method of scoring to obtain maximum likelihood (ML) estimates. This approach to ML estimation, known as Poisson regression, is of considerable practical use since the complex computations can be obtained using standard statistical packages that support IWLS. This leads to ML estimates, their asymptotic covariance matrix, and regression diagnostics that can be used to critically assess the model assumptions and to identify influential observations. A numerical example using both linear and intrinsically nonlinear regression functions is given to illustrate all aspects of Poisson regression analysis. Computational details of the IWLS approach are provided in the Appendix, and a general approach to fitting intrinsically nonlinear models using the statistical system GLIM is described.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.72

POISSON REGRESSION MODELS IN COHORT MORTALITY STUDIES

E. L. Frome D. L. Cragle*
W. R. McLain*

(Abstract of oral presentation given at the 13th International Biometrics Conference, Seattle, WA, July 27 - August 1, 1986)

The use of grouped data Poisson regression models in cohort mortality studies is considered. Observed and expected deaths are cross-classified according to the levels of several risk factors. The first step in the analysis is to develop a mortality profile, using a multiplicative main-effects model. This provides a comparison of the cohort as a whole with the U.S. death rates and a description of the simultaneous effect of each risk factor on the disease of interest. A screening procedure is then used to identify interaction terms that may be important. The relative importance of each interaction term is evaluated using likelihood ratio statistics for marginal and partial association. Interaction terms are classified as definitely needed, definitely not needed, and uncertain. These initial results are then used to guide further analysis.

The use of these methods is illustrated with data from cohort of 28,008 white males who were employed between 1943 and 1947 at three plants in Oak Ridge, Tennessee. Six risk factors are considered: birth year, facility, socioeconomic status, duration of employment, period of followup, and potential radiation exposure. Results are discussed in the context of more general statistical procedures that can be used if further analysis is necessary. This work is part of the Health and Mortality Study of Department of Energy workers being conducted by Oak Ridge Associated Universities with the collaboration of the School of Public Health, University of North Carolina at Chapel Hill.

Research sponsored by the Oak Ridge Associated University of North Carolina at Chapel Hill and U.S. DOE Office of Energy Research.

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.73

MAXIMUM LIKELIHOOD ESTIMATION FOR CYTOGENETIC DOSE-RESPONSE CURVES

E. L. Frome R. J. M. Fry*

(Abstract of oral presentation given at the Biometrics Society Meeting, Atlanta, GA, March 16-19, 1986)

Dose-response curves are used to describe the effect of heavy ion radiation on tumor induction. Experimental data have been obtained for five ion beams over a wide range of LET values. For the k th dose of the j th type of radiation, a number of mice (n_{jk}) are exposed to a single dose of radiation at about the same age (100 days). The dependent variable y_{jk} is the number of mice with Harderian gland tumors about 500 days later. We assume that the y_{jk} 's follow the binomial distribution with expectation $n_{jk}P(d_{jk})$, where

$$P(d) = 1 + (1 - \delta)\exp(-\alpha(d/\theta_j)^\beta)$$

and δ is the probability of observing a tumor at zero dose. For the reference radiation (^{60}Co γ rays), we assume $\theta_1 = 1$, so that θ_j can be interpreted as the RBE for the j th type of heavy ion radiation. The unknown parameters ($\delta, \alpha, \beta, \theta_j, j = 2, \dots, 5$) are estimated using the maximum like-

lihood principle. The ML estimates and their standard deviations are computed using iterative weighted least squares.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

*Biology Division.

1.74

SAMPLE SIZE AND POWER CALCULATIONS FOR TESTS ON POTENTIAL MUTAGENS

D. G. Gosslee

(Abstract of ORNL/TM-10251, January 1987)

For the small proportions typical of many mutation studies, the ability of some statistical tests to detect real effects is poor due to the extreme conservatism of these tests of significance for small proportions. The curve separating the region where the arcsine test is conservative from the region where it is liberal is introduced in this report. In the region where the arcsine test is conservative, the Fisher exact test is much more conservative than the arcsine test.

A modification of the arcsine test is suggested to simplify the specification and calculation of sample size estimates for trials with a small proportion responding. The number of animals required with sufficient power to detect compounds which are mutagenic, as well as the power for a given number of animals, can be calculated easily. The main results are presented for equal numbers of animals in each of two groups with an indication of the formulas for groups of unequal size.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.75

EMPIRICAL RELATIONSHIPS BETWEEN WATERSHED ATTRIBUTES AND HEADWATER LAKE CHEMISTRY IN THE ADIRONDACK REGION

C. T. Hunsaker* S. W. Christensen*
J. J. Beauchamp R. J. Olson*
R. S. Turner* J. L. Malanchuk†

(Abstract of ORNL/TM-9838, December 1986)

Surface water acidification may be caused or influenced by both natural watershed processes and anthropogenic actions. Empirical models and observational data can be useful for identifying watershed attributes or processes that require further research or that should be considered in the development of process models. This study focuses on the Adirondack region of New York and has two purposes: (1) to develop empirical models that can be used to assess the chemical status of lakes for which no chemistry data exist and (2) to determine on a regional scale watershed attributes that account for variability in lake pH and acid-neutralizing capacity (ANC). Headwater lakes, rather than lakes linked to upstream lakes, were selected for initial analysis. The Adirondacks Watershed Data Base (AWDB), part of the Acid Deposition Data Network maintained at Oak Ridge National Laboratory (ORNL), integrates data on physiography, bedrock, soils, land cover, wetlands, disturbances, beaver activity, land use, and atmospheric deposition with the water chemistry and morphology for the watersheds of 463 headwater lakes. The AWDB facilitates both geographic display and statistical analysis of the data.

Both bivariate (correlations and Wilcoxon and Kruskal-Wallis tests) and multivariate analyses were performed. Fifty-seven watershed attributes were selected as input variables to multiple linear regression and discriminant analysis. For model development ~200 lakes for which pH and ANC data exist were randomly subdivided into a specification and a verification data set. Several indices were used to select models for predicting lake pH (31 variables) and ANC (27 variables).

Twenty-five variables are common to the pH and ANC models: four lake morphology, nine soil/geology, eight land cover, three disturbance, and one watershed aspect. An atmospheric input variable (H^+ or NO_3^-) explains the greatest amount of variation in the dependent variable (pH and ANC) for both models. The percentage of watershed in conifers is the next strongest predictor variable. For all headwater lakes in the Adirondacks, ~60% of the lakes are estimated to have an ANC $\leq 50 \mu\text{eq/L}$, and 40% of the lakes have a pH ≤ 5.5 ; these levels believed to be detrimental to some fish species.

Research sponsored by U.S. Environmental Protection Agency.

*Environmental Sciences Division.

†U.S. Environmental Protection Agency, Washington, DC.

1.76

ASSESSMENT OF LINEAR DEPENDENCIES IN MULTIVARIATE DATA

V. E. Kane* R. C. Ward
G. J. Davis†

[Abstract of *SIAM J. Sci. Stat. Comput.* 6(4), 1022 (1985)]

A procedure to identify the linear dependency structure in multivariate data is presented. The linear dependency analysis (LDA) provides a method for assessing the number of dependencies using the eigenvalues of the sample correlation matrix. The dependency structure is then identified from the right singular vectors from a singular value decomposition of the centered and scaled data matrix. An algorithm to identify competing dependencies is given along with procedures for estimating and testing the dependency coefficients. Example data sets from regression, factor analysis, discriminant analysis, and principal component analysis are analyzed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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†Georgia State University, Atlanta, GA.

1.77

**EFFECTS OF CRYOPRESERVATION
ON THE RECOVERY OF
RADIATION-INDUCED CHROMOSOME
ABERRATIONS IN HUMAN
LYMPHOCYTES**

L. G. Littlefield* E. E. Joiner*
S. P. Colyer* E. L. Frome

[Abstract of *Radiation Protection Dosimetry J.* 18(1), 25 (1987)]

We conducted experiments to determine whether irradiated blood samples may be preserved by freezing without compromising the accurate assessment of radiation-induced chromosome aberrations in lymphocyte cultures initiated at later dates. Human whole blood at 37°C was exposed in vitro to 0, 100, 200, or 400 R Cobalt 60 gamma radiation, and lymphocytes were cultured immediately after exposure or after one week's storage at -70°C. A slight depression in cellular proliferation and a significant increase in chromatid breakages were observed in cultures initiated from the previously frozen lymphocytes. In preparations from both fresh and frozen lymphocytes the dose response relationships for radiation-induced dicentrics and acentrics gave a best fit to the linear quadratic dose response model ($Y = \alpha D + \beta D^2$) with no significant differences in the values of the alpha or beta coefficients between the two sets of cultures. This finding provides evidence that lymphocytes bearing radiation-induced chromosome aberrations are not at selective risk for cell death as a result of cryopreservation.

Research sponsored by U.S. DOE Office of Energy Research and Oak Ridge Associated Universities.

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.78

**IDENTIFYING REGIONAL WATER
QUALITY PATTERNS AND THEIR
RELATIONSHIPS WITH
TERRESTRIAL ECOSYSTEMS
AND FISH DISTRIBUTIONS**

T. W. McDaniel* C. T. Hunsaker*
J. J. Beauchamp

(Abstract of ORNL/TM-9916, September 1986)

A multivariate statistical method for analyzing spatial patterns in regional water quality was developed using existing water quality data in the U.S. Environmental Protection Agency's STORET system. Regional patterns of terrestrial ecosystems have been described and mapped for various management and scientific purposes. Most of these methods ignored or placed little emphasis on the regional patterns in aquatic ecosystems even though they are bounded by the terrestrial systems and affected by their functioning. The procedure we used examined geographical patterns for selected water quality variables in Kansas and Georgia. Using multivariate statistical techniques, it was able to distinguish regions with water quality very different from average conditions (as in Georgia) but did not discriminate well between regions that did not have diverse conditions in water quality (as in Kansas). The observed regional water quality patterns were compared with terrestrial ecosystem patterns. In addition, fish distributions were compared with regional patterns in water quality to determine if there was an association between them. In Georgia, water quality patterns were similar to ecosystem patterns and fish distributions, but correlation was not as good for the more homogeneous landscape in Kansas. Identifiable relationships between climate, lithology, terrestrial ecosystems, water quality, and fish distributions should allow the development of an integrated terrestrial-aquatic ecosystem classification scheme that would be a valuable tool for resource management and regional assessment.

Research sponsored by U.S. Environmental Protection Agency.

*Regional Air Pollution Control Agency, Dayton, OH.

†Environmental Sciences Division.

1.79

A SYSTEM FOR THE ANALYSIS OF COHORT MORTALITY DATA

R. McLain* E. L. Frome

[Abstract of paper presented at the SAS Users' Group International 1986 Conference, Atlanta, GA, February 9-12, 1986; Proc. p. 874 (1986)]

A system is developed for the analysis of cohort mortality data. This Mortality Analysis System (MAS) is designed as a research tool in epidemiologic studies. The system allows a researcher to investigate the effect of one or more factors on the mortality of a study cohort. Variables can be categorized as factors to allow for stratification in the analysis. DATA steps and PROC MATRIX are incorporated in the system to produce the output. Person-years, observed deaths, and expected deaths are calculated and cross-classified by the levels of the factors. The resulting data set can be used to compute the standardized mortality ratios (SMR) for each stratum level. Poisson regression models can then be used for further statistical analysis.

Research sponsored by U.S. DOE Office of Energy Research and by Oak Ridge Associated Universities.

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.80

BAYESIAN APPROACHES TO THE DESIGN OF COMPUTATIONAL EXPERIMENTS

T. J. Mitchell

(Abstract of a talk presented at the Workshop on Efficient Data Collection: Design of Computational Experiments, University of California, Los Angeles, CA, January 8-10, 1986)

In a computational experiment, the data are produced by a computer program that models a physical system. The experiment consists of a set of model runs; the design of the experiment specifies the choice of inputs to the program for each run. In this talk, I discuss Bayesian approaches to quantifying uncertainty about the output corresponding to inputs that have not yet been

made in the context of several classes of computational experiments. This leads to design procedures based on optimizing measures of information.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.81

ALGORITHMS FOR BAYESIAN VARIABLE SELECTION IN REGRESSION

T. J. Mitchell J. J. Beauchamp

(Abstract of oral presentation given at the Computer Science and Statistics: 18th Symposium on the Interface, Fort Collins, CO, March 20-21, 1986)

We have developed a Bayesian approach to the problem of deciding which subset of a proposed set of k predictor variables to include in a linear regression model that is to be used for prediction. The direct implementation of this method requires the computation of the usual regression statistics for each of the 2^k possible submodels. We present here a branch-and-bound method which yields the same results much more quickly by eliminating from consideration those submodels which are destined to have negligible posterior probability. Implementation of the algorithm on the Cray X-MP supercomputer is discussed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.82

BAYESIAN VARIABLE SELECTION IN REGRESSION

T. J. Mitchell J. J. Beauchamp

[Abstract of ORNL-6328, January 1987; also J. Am. Stat. Assoc. (in press)]

This paper is concerned with the selection of subsets of "predictor" variables in a linear regression model for the prediction of a "dependent" variable. We take a Bayesian approach and assign a probability distribution to the dependent variable through a specification of prior distribu-

tions for the unknown parameters in the regression model. The appropriate posterior probabilities are derived for each submodel and methods are proposed for evaluating the family of prior distributions. Examples are given that show the application of the Bayesian methodology.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.83

A BAYESIAN APPROACH TO THE DESIGN AND ANALYSIS OF COMPUTATIONAL EXPERIMENTS

T. J. Mitchell M. D. Morris

(Abstract of oral presentation presented at the University of Tennessee, Knoxville, TN, November 6, 1986, entitled "Bayesian Approaches to the Design of Computational Experiments"; at the Workshop on Design for Computer Experiments, Champaign, IL, April 27-29, 1987; at the American Statistical Association 1987 Joint Statistical Meetings, San Francisco, CA, August 17-20, 1987; and at the Second Workshop on Design for Computer Experiments, Santa Fe, NM, September 21-23, 1987; and to be presented at the Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21-23, 1987)

In a computational experiment, the data are produced by a computer program that models a physical system. The experiment consists of a set of model runs; the design of the experiment specifies the choice of program inputs and parameters for each run. Experimental goals are often similar to those in physical experiments: prediction, optimization, factor screening, etc. However, standard statistical approaches to experimental design and data analysis do not necessarily carry over to computational experiments.

This talk centers on the problem of fast predictive approximation (interpolation), the goal of which is to devise a design/analysis method which will provide predictions of model output for input and parameter values not run. We adopt a Bayesian approach as the basis for the analysis. Uncertainty about the response function is quantified by choosing a class of probability distributions over the function space. This leads to design procedures based on maximizing the expected reduction in "amount of uncertainty," where the latter can be defined formally in terms

of properties of the posterior distribution. We shall discuss the construction of optimal design in this context and shall demonstrate the approach with some examples.

Research sponsored by U.S. Department of Energy.

1.84

A COMPUTER PROGRAM FOR THE DESIGN OF GROUP TESTING EXPERIMENTS

T. J. Mitchell D. S. Scott*

[Abstract of *Communications in Statistics* (in press)]

This paper describes a computer program *GTEST* for designing group testing experiments. The outcome of a test on a group of items is either "negative" (if all items in the group are good) or "positive" (if at least one of the items is defective). *GTEST* is based on a Bayesian approach. At each stage, it attempts to maximize (nearly) the expected reduction in the "entropy," which is a quantitative measure of the amount of uncertainty about the state of the items. The user controls the procedure through specification of the prior probabilities of being defective, restrictions on the construction of the test group, and priorities that are assigned to the items. The nominal prior probabilities can be modified adaptively, to reduce the sensitivity of the procedure to the proportion of defectives in the population.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Intel Scientific Computers, Beaverton, OR.

1.85

DETECTION OF ASSOCIATIONS BETWEEN DISEASES IN ANIMAL CARCINOGENICITY EXPERIMENTS

T. J. Mitchell B. Turnbull*
D. A. Wolf*

(Abstract of oral presentation given at the 13th International Biometrics Conference, Seattle, WA, July 27 - August 1, 1986)

The detection of associations between different tumor types in animal carcinogenesis

experiments is important to the understanding of disease mechanisms. It also has important implications for regulatory decisions, especially in the case of negative associations, where exposure to some substances may appear to increase the incidence of one type of tumor while decreasing the incidence of another. It is well known that, even after stratification by treatment and age, spurious negative associations can occur because of lethality of the diseases. We examine this problem in the context of a crude model in which diseases can be present in only two states: nonlethal or lethal. The progression of a disease within any animal is from absence to nonlethal presence to lethal presence. We define two diseases to be "independent" if their corresponding progression processes are statistically independent. It can be shown that in the usual analysis, which considers only the 2×2 tables formed by classifying each disease as present or absent in every age-treatment stratum, two independent diseases will appear to be negatively correlated. Here we present an alternative approach based on our model which leads to consideration of a sequence of 3×3 tables. From this, a conditional test of the hypothesis of independence of two diseases can be constructed. The method is illustrated by an application to data from a radiocarcinogenesis study.

Research sponsored by Systems Damage Program, U.S. DOE Office of Health and Environmental Research.

*Cornell University, Ithaca, NY.

†University of Wisconsin, Madison, WI.

1.86

A SEQUENTIAL EXPERIMENTAL DESIGN FOR ESTIMATING A SCALE PARAMETER FROM QUANTAL LIFE TESTING DATA

M. D. Morris

[Abstract of *Technometrics* 29(2), 173 (1987); also talk presented at the Southern Regional Education Board/Southern Regional Committee on Statistics Summer Research Conference, Gatlinburg, TN, June 14-19, 1987]

A quantal life testing experiment in which failures can be detected only at inspection is discussed. If each unit is inspected only once, the

data acquired are censored; the inspection time is a lower limit on failure time if the unit has not yet failed or an upper limit if it has failed. The resulting data can be used to estimate the distribution of times to failure. A sequential experimental plan for use when the distribution of times to failure is known apart from a scale parameter is introduced. Advantages of this design over other sequential plans include a computationally simple asymptotic analysis and the ability to know ahead of time the number of units to be inspected at each stage. Under certain conditions, the design is shown to be asymptotically efficient, and finite sample efficiencies are presented for the exponential distribution.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.87

NOTES ON THE EFFECT OF DOSE UNCERTAINTY

M. D. Morris

(Abstract of talk presented at the NATO RSG5 Meeting, Portsmouth, England, May 11, 1987)

The apparent dose-response relationship between amount of exposure to acute radiation and level of mortality in humans is affected by uncertainties in the dose values. Some possible magnitudes of these effects are numerically demonstrated.

Research sponsored by Defense Nuclear Agency.

1.88

TWO-STAGE FACTOR SCREENING PROCEDURES USING MULTIPLE GROUPING ASSIGNMENTS

M. D. Morris

[Abstract of *Comm. Stat.* (in press)]

A generalization of the group screening technique for finding the non-negligible factors in a first order model is presented. In conventional screening designs, each factor is assigned to a single factor group, and the sum of effects associ-

ated with each group is estimated in the first stage. The new designs assign a factor to multiple groups in the first stage. An individual effect is estimated in the second stage only if each group to which the corresponding factor is assigned is "active" in the first stage. The performance of these designs is compared to conventional group screening designs for cases in which the direction of each factor, if active, is assumed known *a priori* and measurement error is negligible.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.89

SENSITIVITY ANALYSIS OF A NUMERICALLY SIMULATED $HgCdTe$ SOLIDIFICATION PROCESS BY STATISTICAL METHODS

M. D. Morris V. Alexiades

(Abstract of ORNL-6210, February 1986)

Statistical response surface methodology is applied to the problem of determining simple approximations for outputs as functions of input parameter values in a numerical simulation of the solidification of a mercury-cadmium-telluride alloy. The approximating polynomials are then differentiated with respect to parameter values to determine sensitivities. A table of percent changes in output values as a result of one per cent changes in parameter values is presented. The empirical procedure used constitutes an unorthodox application of the statistical methodology, but it is easy to use, quite generally applicable and very effective.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and by Microgravity Science and Applications Division of the National Aeronautics and Space Administration.

1.90

A COMPARISON OF DOSE-RESPONSE MODELS FOR DEATH FROM HEMATOLOGICAL DEPRESSION

M. D. Morris T. D. Jones*

[Abstract of *Int. J. Radiation Biology* (in press); also talk presented at the NATO RSG5 Meeting, Portsmouth, England, May 11, 1987]

Many radiation-induced lethality experiments have been published for various mammalian species. From those studies a subset of studies reflecting useful biological and physical variables has been compiled into a database suitable to study interspecific variability of radiosensitivity, dose-rate dependence of sensitivity, dose-response behavior within each experiment, etc.

The data compiled were restricted to continuous and nearly continuous exposures to photon radiations having source energies above 100 keV. Also, photon source energy, exposure geometry, and body weight considerations were used to select studies where the dose to hematopoietic marrow was nearly uniform, i.e. $< \pm 20\%$. The data base reflects 13 mammalian test species ranging from mice to cattle.

Some 211 studies were compiled but only 105 were documented in adequate detail to be useful in development and evaluation of dose-response models of interest to practical human exposures. Of the 105 studies, 70 were for various rodent species, and 35 were for nonrodent groups ranging from standard laboratory primates (body weight ~ 5 kg) to cattle (body weight 375 kg).

This paper considers seven different dose-response models which are tested for validity against those 105 studies. The dose-response models included a right-skewed extreme value, a left-skewed extreme value model, log-logistic, log-probit, logistic, probit, and Weibull models.

In general, the log transformed models did not improve model performance and the extreme value models did not seem consistent with the preponderance of the data. Overall, the probit and the logistic models seemed preferable over the Weibull model.

The shape of the dose-response function, the point of normalization, e.g., the LD₅₀ value for man, and a statistical analysis of the effects from different biological and physical variables will help to assess the radiosensitivity of man in terms of the many published animal studies.

Research sponsored by Defense Nuclear Agency.
*Health and Safety Research Division.

1.91

DOSE-RESPONSE MODEL SELECTION FOR ANIMAL STUDIES AND PREDICTION OF HUMAN RESPONSE LEVELS

M. D. Morris T. D. Jones*

(Abstract of oral presentation given at the Defense Nuclear Agency Workshop on the LD₅₀ for Healthy Young Adults Actively Irradiated with Low-LET Whole-Body Radiation, Arlington, VA, March 9-10, 1987)

Our recent work in the comparison of parametric models for use in animal radiation mortality studies is reviewed, along with predictions of lethal doses for man based on these models.

Research sponsored by Defense Nuclear Agency.
*Health and Safety Research Division.

1.92

PREDICTION OF THE MORTALITY DOSE-RESPONSE RELATIONSHIP IN MAN

M. D. Morris T. D. Jones*

(Abstract of talk presented at the NATO RSG5 Meeting, Portsmouth, England, May 11, 1987)

Based upon an extensive data base including 100 separate animal studies, an estimate of the mortality dose-response relationship due to continuous photon radiation is predicted for 70 kg man. The model used in this prediction exercise includes fixed terms accounting for effects of body weight and dose rate, and random terms accounting for inter- and intra-species variation and experimental error. Point predictions and 95% prediction intervals are given for the LD₀₅,

LD₁₀, LD₅₀, LD₇₅, LD₉₀, and LD₉₅, for dose rates ranging from 1 to 50 R/min.

Research sponsored by Defense Nuclear Agency.
*Health and Safety Research Division.

1.93

INDEX SETS IN ANOVA MODELS AND THEIR USE IN ANOVA COMPUTATIONS

G. Ostronchov

(Abstract of oral presentation given at the Computer Science and Statistics: 18th Symposium on the Interface, Fort Collins, CO, March 20-21, 1986)

Each model term in the effects ANOVA model has a set of indices associated with it. A notation that is based on these index sets is described. The index sets allow a concise and computationally convenient description of the model matrix and linear dependencies between blocks of columns in the model matrix corresponding to model terms. An application of this notation is the development of a sparse matrix algorithm for fitting large ANOVA models that is both fast and storage efficient.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.94

PARALLEL COMPUTING ON A HYPERCUBE: AN OVERVIEW OF THE ARCHITECTURE AND SOME APPLICATIONS

G. Ostronchov

(Abstract of paper presented to the 19th Symposium on the Interface of Computer Science and Statistics, Philadelphia, PA, March 8-11, 1987)

A hypercube parallel computer is a network of processors, each with only local memory, whose activities are coordinated by messages the processors send between themselves. The interconnection network corresponds to the edges of an n -dimensional cube with a processor at each vertex. This talk will describe the hypercube archi-

texture and its relation to other distributed-memory message-passing multiprocessors. Some aspects of designing parallel algorithms for the hypercube and some applications in statistical computing will also be discussed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.95

ACCURACY OF APPROXIMATE CONFIDENCE BOUNDS COMPUTED FROM INTERVAL CENSORED WEIBULL DATA

G. Ostrovnich W. Q. Meeker, Jr.*

(Abstract of paper presented at the 1986 Joint Statistical Meeting, Chicago, IL, August 16-21, 1986)

Interval censored data arise frequently in industrial life tests and in other applications. Maximum likelihood estimation provides a convenient means for making inferences on important distribution properties like quantiles and failure probabilities. The asymptotic normal distribution of the maximum likelihood estimators provides a simple method of setting approximate confidence bounds on these quantities. Inverting likelihood ratio tests is another alternative. This paper uses Monte Carlo simulation to investigate the finite sample properties of maximum likelihood estimators of Weibull parameters and quantiles from interval censored data. We evaluate the accuracy of large sample one- and two-sided confidence bounds based on asymptotic normal theory and compare their accuracy with those obtained by inverting likelihood ratio tests. Our results show that the intervals based on inverting a likelihood ratio test have coverage properties that are closer to the nominal values.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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1.96

ACCURACY OF APPROXIMATE CONFIDENCE BOUNDS COMPUTED FROM INTERVAL CENSORED WEIBULL AND LOGNORMAL DATA

G. Ostrovnich W. Q. Meeker, Jr.*

[Abstract of *J. Stat. Comput. Simula.* (in press)]

Interval censored data arise frequently in industrial life tests and other applications. Maximum likelihood estimation provides a convenient means for making inferences on important distribution properties like quantiles and failure probabilities. The asymptotic normal distribution of the maximum likelihood estimators provides a simple method of setting approximate confidence bounds on these quantiles. Inverting likelihood ratio tests is another alternative. This paper uses Monte Carlo simulation to investigate the finite sample properties of maximum likelihood estimators of Weibull and lognormal parameters and quantiles from interval censored data. We evaluate the accuracy of large sample one- and two-sided confidence bounds based on asymptotic normal theory and compare their accuracy (with respect to coverage probability) to those obtained by inverting likelihood ratio tests. Even though these procedures are asymptotically equivalent, our results show that the intervals based on inverting a likelihood ratio test generally have coverage properties that are close to the nominal confidence levels.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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1.97

CONVEX SETS IN M: MUM-DISTANCE ESTIMATION

R. L. Schmoyer

[Abstract of *Commun. Statist.-Theory Meth.* 15(12), 3625 (1986)]

Let X be a normed vector space, let C be a subset of X , and let $P_C(z)$ denote the set of pro-

jections of a point $z \in X$ onto C . Assume that for all $z \in X$, $P_C(z)$ is nonempty. C will be called *unified* if $\hat{\mu} \in P_C(z)$, $z \in X$, and $\mu \in C$ imply $\|\hat{\mu} - \mu\| \leq \|z - \mu\|$. In the context of estimation, μ is an unknown parameter assumed *a priori* to be in C , and z is an unconstrained data-based estimate of μ . If C is unified, then $\hat{\mu}$ is closer to both $\mu \in C$ (assumption) and z (data) than μ and z are to themselves. In an inner product space a set is unified if and only if it is convex. This is not the case, however, if the norm does not admit an inner product. In this paper we characterize those spaces in which convex sets must be unified, and partially characterize those spaces in which unified sets must be convex. An example involving M -estimation is discussed.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.98

DOSE-RESPONSE ANALYSIS UNDER UNIMODALITY OF RESPONSE-TO-DOSE

R. L. Schmoyer

(Abstract of paper presented at the Conference on Order-Restricted Inference, Iowa City, IA, September 11-13, 1985; Proc. p. 125, *Advances in Order-Restricted Statistical Inference*, Springer-Verlag, 1986)

A dose-response curve π is sigmoidal if it is nondecreasing and there is a point M to the left of which π is convex and to the right of which π is concave. If π is sigmoidal, then the response-to-dose ratio $\pi(x)/x$ is unimodal and maximized at a point $H \geq M$. If $\pi(0)$ is known, if H is known, and if $x_0 \leq x \leq H$, then an upper confidence bound (UCB) for $\pi(x_0)$ can be constructed from a UCB for $\pi(x)$. We consider unimodality of response-to-dose as a basis for inference about π in the setting of quantal bioassay. A lower confidence bound for H and a UCB for $\pi(x_0)$ when H is unknown are obtained. A maximum-violator algorithm with guaranteed convergence is given for computing the maximum likelihood estimates of response probabilities.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.99

LINEAR INTERPOLATION WITH A NONPARAMETRIC ACCELERATED FAILURE-TIME MODEL

R. L. Schmoyer

[Abstract of *J. Am. Stat. Assoc.* (in press)]

Assuming a nonparametric accelerated failure-time model, a method is proposed for interpolating low-stress response probabilities on negative sloping line segments in the stress-failure-time plane. The method, which is analogous to linear interpolation in dose-response studies, results in simultaneous extrapolation ahead in time and down in stress. In the two-sample (two stress level) setting, a goodness-of-fit test of the nonparametric model is considered, and hypothesis tests are proposed for testing two conditions, which in addition to the assumed model, must be met for the method to be valid. An example involving censored data is discussed.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

1.100

THE CONTINUED FRACTION FOR $\ln\Gamma(z)$: A STIELTJES CONJECTURE

L. R. Shenton* K. O. Bowman

[Abstract of *J. Stat. Comp. Simu.* 23(1&2), 133 (1985)]

The series part of $\ln\Gamma(z)$ has a Stieltjes type continued fraction representation. Stieltjes conjectured that the asymptotic form for the s partial numerator was $s^2/16$. Numerical evidence is given to support this unproven conjecture.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*University of Georgia, Athens, GA.

1.101

PRIORITIZATION TECHNIQUES BASED ON STOCHASTIC PAIRED COMPARISONS

V. R. R. Uppuluri

(Abstract of paper presented at the American Statistical Association 1987 Joint Statistical Meetings, San Francisco, CA, August 17-20, 1987)

In 1977 Thomas L. Saaty introduced a method of assigning weights to categories based on data on paired comparisons. If we let a_i denote the relative importance of the object being classified into the i^{th} category, as opposed to the j^{th} category, then it is assumed that $a_j = 1/a_i$. The normalized eigenvector associated with the largest eigenvalue of this reciprocal matrix is suggested as the vector of weights associated with the categories. In this paper, we extend this technique when the data is based on stochastic paired comparisons.

Research sponsored by U.S. Department of Energy.

1.102

MEASURES OF DIVERSITY BASED ON FUZZY MULTINOMIAL DISTRIBUTIONS

V. R. R. Uppuluri T. N. Bhargava*

(Abstract of a paper presented at the 46th Session of the International Statistical Institute, Tokyo, Japan, September 7-16, 1987)

In this paper a fuzzy multinomial distribution is defined. Based on this, the entropy and a quadratic measure of diversity of a multinomial distribution are defined. These are illustrated by a numerical example, and problems for further study are indicated.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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1.103

ALGORITHM 633: AN ALGORITHM FOR LINEAR DEPENDENCY ANALYSIS OF MULTIVARIATE DATA

R. C. Ward G. J. Davis*
V. E. Kane†

[Abstract of *ACM Trans. Math. Software* 11(2), 170 (1985)]

The Linear Dependence Analysis (LDA) algorithm is designed to analyze the potential for declaring linear dependencies between variables in multivariate data. The algorithm provides the user with information to help determine the number of dependencies and computes competing dependency structures for assignments of variables yielding similar results. Computation time may be saved by computing only the "benchmark" solution, a near-optimal solution, which also provides information about "strong" and "weak" variables in the analysis.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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1.104

A NOTE ON OPTIMAL ALLOCATION AND AN ORDERING OF THE FAMILY OF BETA PRIOR DISTRIBUTIONS

T. Wright

[Abstract of *Comm. Stat. Theory & Methods* (in press)]

Because the uniform (0,1) distribution is flat our intuition often leads us to consider it as the least informative in the family of beta distributions as a prior for the parameter P . This thinking derives from what is often called Bayes' Postulate. A simple concept, also based on intuition, is introduced which leads to a simple way of determining which of two beta priors gives "more information" in the context of estimating the difference between two proportions. For the new concept, the amount of prior information on a parameter depends not only on the dispersion of

the prior distribution, but also on the expected dispersion of the sample distribution. One consequence of this new concept is that the uniform (0,1) distribution is shown to give more prior information in some cases than some other distributions in the family of beta (α, β) priors. Another is that for a given sample size n , we are able to define a linear ordering on this family of probability distributions. With the linear ordering for a given n , it appears that there is no least informative beta prior.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.105

**A SIMPLE METHOD FOR PROBABILITY
PROPORTIONAL TO SIZE (πps)
SAMPLING WITHOUT REPLACEMENT
BASED ON RANKS**

T. Wright

(Abstract of ORNL/TM-10398, June 1987; also oral presentation presented at the American Statistical Association 1987 Joint Statistical Meetings, San Francisco, CA, August 17-20, 1987)

There can be gains in estimation efficiency over equal probability and unequal probability with replacement sampling methods when one makes use of auxiliary information for probability proportional to size without replacement ($\pi pswor$) sampling methods. Such methods are often complex to execute, particularly when the sample size n exceeds 2. Also, appropriate auxiliary information may not be available. When the population units can be ranked according to the variable of interest, we demonstrate that there can be gains in estimation efficiency with a very simple $\pi pswor$ sampling strategy based on ranks for all sample sizes n where the population size $N = 2kn$ (k a positive integer).

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.106

**AN EMPIRICAL INVESTIGATION
OF THE USE OF RANKS
IN πps SAMPLING**

T. Wright

(Abstract of a paper presented at the 46th Session of the International Statistical Institute, Tokyo, Japan, September 7-16, 1987)

Let $U_1, U_2, \dots, U_N$ be the N units of a finite population and let (Y_i, x_i) be a vector of nonnegative components associated with the i^{th} unit, where the x 's are known and the y 's are unknown. A sample of fixed size $n (< N)$ is to be selected to estimate the unknown population total

$Y = \sum_{i=1}^N y_i$. Let π_i be the probability of sample inclusion for the i^{th} unit. Many have realized improvements in efficiency by taking $\pi_i = np_i$ where $p_i = x_i / \sum_{j=1}^N x_j$ is a normed measure of

size for the i^{th} unit. Such plans, called probability proportional to size (πps) sampling plans, can be difficult to execute when sampling is without replacement (wor), particularly when $n > 2$.

When a suitable variable x , which is directly proportional to the variable of interest y , is not available, one may know how to rank units reasonably well relative to the unknown y values before sample selection. When such ranking is possible, we introduce a simple and efficient $\pi pswor$ sampling plan for general n using the ranks as the known x measures of size.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.107

**DOES THE UNIFORMED PERSON
ALWAYS USE A UNIFORM
PRIOR DISTRIBUTION?**

T. Wright

(Abstract of talk presented to the Statistics Department, University of Tennessee, Statistics Department, Knoxville, TN, November 20, 1986)

We consider a possible Bayesian approach for two common problems.

In the first, assume a finite population of N items where a certain unknown proportion, P , of the items are, say, defective. Usually one wants to estimate P by using sampling techniques. Sometimes we also want to determine the probability of missing any defectives. Using prior information, one solution is to take a Bayesian approach. When we assume no prior information, tradition tells us to take a uniform (flat) prior distribution on P and the Bayesian approach still seems possible.

In the second problem, assume two large populations where one wants to estimate $P_1 - P_2$. We assume a prior distribution on P_1 and another on P_2 . In a Bayesian setting, we are able to consider the concept of the amount of information given by one prior distribution relative to another by determining an optimal allocation of the sample. Other factors being equal, we say that the prior distribution on P_1 is more informative than the prior distribution on P_2 if the required optimal sample size from population one is less than the required optimal sample size from population two. For a given overall sample size, this concept appears to order the family of beta distributions. Initial results suggest a paradox; namely, that the uniform prior distribution is not necessarily the least informative.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

I.108

**ON A CENTRAL LIMIT THEOREM
FOR VARIABLE SIZE SIMPLE
RANDOM SAMPLING FROM
A FINITE POPULATION**

T. Wright

(Abstract of ORNL/TM-9864, February 1986)

This paper introduces a sampling plan for finite populations herein called "variable size simple random sampling" and compares properties of estimators based on it with results from the usual fixed size simple random sampling without replacement. Necessary and sufficient conditions for the limiting distribution of the sample total (or sample mean) to be normal are given.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.109

**SURVEY SAMPLING: A
USEFUL TOOL FOR
SCIENTIFIC INVESTIGATION**

T. Wright

[Abstract of *ORNL Review* 19(4), 32 (1986)]

This nontechnical article gives a general discussion of classical sampling techniques and illustrates applications for selected projects at ORNL. The article also argues for the need to study the theoretical properties of various sampling and estimation plans and the need to introduce new ones better suited for existing and new situations.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

Computer Science

1.110

**QR FACTORIZATION OF A DENSE
MATRIX ON A SHARED-MEMORY
MULTIPROCESSOR**

E. Chu^{*} A. George

(Abstract of ORNL/TM-10581, October 1987)

A new algorithm for computing an orthogonal decomposition of a rectangular $m \times n$ matrix A on a shared-memory parallel computer is described. The algorithm uses Givens rotations and has the feature that its synchronization cost is low. In particular, for a multiprocessor having p processors, an analysis of the algorithm shows that this cost is $O(n^2/p)$ if $m/p \geq n$, and $O(mn/p^2)$ if $m/p < n$. Note that in the latter case, the synchronization cost is smaller than $O(n^2/p)$. Therefore, the synchronization cost of the algorithm proposed in this article is bounded by $O(n^2/p)$ when $m > n$. This is important for machines where synchronization cost is high and when $m \gg n$. Analysis and experiments show that the algorithm is effective in balancing the load and producing high efficiency (speed-up).

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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1.111

**IMPLEMENTING FRACTURE MECHANICS
ANALYSIS ON A DISTRIBUTED-MEMORY
PARALLEL PROCESSOR**

J. A. Clinard^{*} G. A. Geist

(Abstract of ORNL/TM-10367, March 1987)

As part of an exploratory studies initiative at Oak Ridge National Laboratory, a parallel algorithm was developed and implemented for finite-element fracture mechanics. It was actually implemented on an Intel iPSC hypercube, although the algorithm was designed for any distributed-memory parallel computer with mes-

sage passing primitives. A p -frontal method was developed for the solution of the equilibrium equations. This method required only $\log_2 p$ communication exchanges between processors during solution. On four processors, the parallel code solved a sample problem 2.7 times faster than the serial code, ORVIRT.PC, from which it was derived.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

^{*}Engineering Technology Division.

1.112

**COLUMN LU FACTORIZATION
WITH PIVOTING ON A
HYPERCUBE MULTIPROCESSOR**

G. J. Davis^{*}

(Abstract of ORNL-6219, November 1985)

A column-oriented algorithm is presented for LU factorization with partial pivoting. Two different mappings of columns to processors are considered. Forward and back substitution algorithms to use the factorization for solving linear systems are developed. Timing data, including processor utilization and load balancing, are provided by a hypercube simulator.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

^{*}Georgia State University, Atlanta, GA.

1.113

**A HYPERCUBE IMPLEMENTATION
OF THE IMPLICIT DOUBLE
SHIFT QR ALGORITHM**

G. J. Davis^{*} R. E. Funderlic^{*}
G. A. Geist

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 619 (1987)]

A parallel implementation of the implicit double shift QR algorithm for finding the eigenvalues

of dense unsymmetric matrices is presented along with an algorithm to reduce the original matrix to upper Hessenberg form on a hypercube multiprocessor. Our preliminary results show that these algorithms can achieve reasonable efficiencies even with slow hypercube communication.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

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†North Carolina State University, Raleigh, NC.

1.114

MOLECULAR DYNAMICS OF A MODEL POLYMER ON A HYPERCUBE PARALLEL COMPUTER

J. B. Drake A. K. Hudson
E. Johnson* D. W. Noid*
G. A. Pfeffer† S. Thompson

[Abstract of *Computers and Chemistry* (in press)]

In this paper, we discuss the implementation and solution of molecular dynamics polymer models on the Intel iPSC Hypercube parallel computer. We first describe a model problem whose inherent parallelism can be exploited effectively and which is therefore amenable to parallel solution. We next discuss the salient features of the hypercube programs that were used to solve the model problem. Finally, we present results which demonstrate that the efficiencies of the solutions approach 100% as the number of atoms processed by each hypercube processor is increased for the problem in question. The results demonstrate that parallel solutions of polymer problems using a hypercube architecture offer potentially significant savings over sequential solutions.

Research sponsored by U.S. Department of Energy.

*Chemistry Division.

†University of Nebraska at Omaha, Omaha, NE.

1.115

IMPLEMENTATION OF A 3-D NONLINEAR MHD CALCULATION ON THE INTEL HYPERCUBE

J. B. Drake W. F. Lawkins
B. A. Carreras* H. R. Hicks†
V. E. Lynch†

(Abstract of ORNL-6335, August 1987)

As part of an exploratory study of the suitability of hypercube multiprocessors for scientific computations, the non-linear magnetohydrodynamics (MHD) code RSF was parallelized for use on an Intel iPSC hypercube. This report presents the numerical algorithm of RSF and the techniques used to obtain parallelism without sacrificing the numerical properties of the serial algorithm. Timing results are presented for a sample problem.

Research sponsored by U.S. DOE Exploratory Studies Program.

*Fusion Energy Division.

†Computing and Telecommunications Division.

1.116

A MESSAGE-PASSING MULTIPROCESSOR SIMULATOR

T. H. Dunigan

(Abstract of ORNL/TM-9966, May 1986)

The structure and use of a message-passing multiprocessor simulator are described. The simulator provides a multitasking environment for the development of algorithms for parallel processors using either shared or local memories. The simulator may be used from C or FORTRAN and provides a library of subroutines for task control and message passing. The simulator produces a trace file that can be used for debugging, performance analysis, or graphical display.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.117

A PORTABLE HYPERCUBE SIMULATOR**T. H. Dunigan**

(Abstract of ORNL/TM-10410, July 1987)

The structure and use of a hypercube simulator that runs on most UNIX systems is described. The simulator uses a library of message-passing routines and multiple user processes, written in either C or FORTRAN, to provide an environment for the development and testing of algorithms for hypercube parallel processors. The simulator produces a trace file that can be used for debugging, performance analysis, or graphical display. A version of the simulator that uses the shared memory of a sequent multiprocessor is also described.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.118

**DENELCOR HEP
MULTIPROCESSOR SIMULATOR****T. H. Dunigan**

(Abstract of ORNL/TM-9971, June 1986)

The structure and use of a simulator for the Denelcor HEP multiprocessor are described. The simulator provides a multitasking environment for the development of parallel programs in C or FORTRAN using a library of subroutines that simulate the parallel programming constructs available on the HEP, a shared-memory multiprocessor. The simulator also provides a trace file that can be used for debugging, performance analysis, or graphical display.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.119

PERFORMANCE OF THREE HYPERCUBES**T. H. Dunigan**

(Abstract of ORNL/TM-10400, May 1987; also paper entitled "Hypercube Performance," presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 178 (1987))

The performance of three commercially available hypercube parallel processors is analyzed. Computation and communication performance for a number of low-level benchmarks are presented for the Ametek S14 hypercube, the Intel iPSC hypercube, and the Ncube hypercube.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.120

**MODIFIED CYCLIC ALGORITHMS
FOR SOLVING TRIANGULAR
SYSTEMS ON DISTRIBUTED-MEMORY
MULTIPROCESSORS****S. C. Eisenstat*****M. T. Heath****C. S. Henkel†****C. H. Romine**(Abstract of *SIAM J. Sci. Stat. Comput.* (in press))

New parallel algorithms and comparative test results are given for solving triangular systems of linear equations on distributed-memory multiprocessors. These results supplement those given in a previous paper. All of the new algorithms are variations on the cyclic algorithms discussed previously. The new algorithms are shown to provide substantial performance improvements.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research; by Office of Naval Research; by National Science Foundation; and by Nuclear Engineering and Health Physics Fellowship Program administered by Oak Ridge Associated Universities.

*Yale University, New Haven, CT.

†North Carolina State University, Raleigh, NC.

1.121

EFFICIENT PARALLEL LU FACTORIZATION WITH PIVOTING ON A HYPERCUBE MULTIPROCESSOR

G. A. Geist

[Abstract of ORNL-6211, October 1985; also *Parallel Computing* (in press)]

A message-passing parallel algorithm is developed for forming the LU factors of general non-singular matrices on a hypercube multiprocessor. Partial pivoting is performed to ensure numerical stability, but the scheduling of tasks is such that the pivot search in the parallel algorithm is completely masked. Empirical tests show that the load imbalance produced by random pivoting causes a 5%–14% increase in execution time. A complementary parallel triangular solution algorithm is also given. Comparisons with the non-pivoting case are used to demonstrate the efficiency of this new algorithm.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.122

SOLVING FINITE ELEMENT PROBLEMS WITH PARALLEL MULTIFRONTAL SCHEMES

G. A. Geist

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29–30, 1986; Proc. SIAM Philadelphia, p. 656 (1987)]

A parallel multifrontal scheme is presented that uses a method we call the super boundary element technique. This technique reduces the amount of communication required during the factorization to $\log p$ exchanges, where p is the number of processors, and no communication is required in the parallel back substitution. Results from a finite element fracture analysis problem are used to illustrate this method.

Research sponsored by Applied Mathematical Sciences, U.S. DOE Office of Energy Research.

1.123

MATRIX FACTORIZATION ON A HYPERCUBE MULTIPROCESSOR

G. A. Geist M. T. Heath

[Abstract of paper presented at the First Conference on Hypercube Multiprocessors, Knoxville, TN, August 26–27, 1985; Proc. p. 161 (1986)]

This paper is concerned with parallel algorithms for matrix factorization on distributed-memory, message-passing multiprocessors, with special emphasis on the hypercube. We consider both Cholesky factorization of symmetric positive definite matrices and LU factorization of nonsymmetric matrices using partial pivoting. We also consider the use of the resulting triangular factors to solve systems of linear equations by forward and back substitutions. Efficiencies of various parallel computational approaches are compared in terms of empirical results obtained on an Intel iPSC hypercube.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.124

PARALLEL ALGORITHMS FOR MATRIX COMPUTATIONS

G. A. Geist M. T. Heath
E. Ng

[Abstract of book chapter in *The Characteristics of Parallel Algorithms*, pp. 233–251, L. Jamieson, D. Gannon, and R. Douglass, Ed., MIT Press (1987)]

The fundamental importance of linear algebra problems in science and engineering has placed algorithms for matrix computations in the forefront of research on parallel algorithms. We review the characteristics of parallel architectures that most strongly affect the design and performance of parallel algorithms for various matrix computations. These issues point toward a preliminary taxonomy of parallel matrix algorithms based on problem characteristics, basic solution methods, and specific features of target architectures. More detailed classification schemes

require finer analysis of the interplay among algorithms, architectures, and applications.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.125

A PARTITIONING STRATEGY FOR SPARSE MATRIX FACTORIZATION ON MULTIPROCESSORS

G. A. Geist E. Ng

(Abstract of oral presentation to be presented at the Gatlinburg X International Conference on Numerical Algebra, Fairfield Glade, TN, October 19-23, 1987)

This talk deals with the problem of partitioning the work of parallel factorization of a large sparse positive definite matrix A on a multiprocessor system. It is assumed that the system supports some form of interprocessor communication either through message passing or through shared memory.

The goal of this partitioning strategy is to achieve load balancing and a high degree of concurrency between the processors while reducing the amount of processor-to-processor data communication. The task assignment strategy is based on the structure of an elimination tree. The strategy presented here can be applied to arbitrarily unbalanced trees. Unbalanced elimination trees are often produced by minimum degree (MD) orderings of irregular problems. They have even been observed for MD orderings of some regular grid problems. Since MD orderings are considered the best fill reducing orderings available for general problems, we developed an algorithm for partitioning the tasks of the factorization which works even when the problem has been ordered by minimum degree.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.126

LU FACTORIZATION ALGORITHMS ON DISTRIBUTED-MEMORY MULTIPROCESSOR ARCHITECTURES

G. A. Geist C. H. Romine

[Abstract of ORNL/TM-10383, March 1987; also *SIAM J. Sci. Stat. Computing* (in press)]

In this paper, we consider the effect that the data storage scheme and pivoting scheme have on the efficiency of LU factorization on a distributed-memory multiprocessor. Our presentation will focus on the hypercube architecture, but most of our results are applicable to distributed-memory architectures generally. We restrict our attention to two commonly used storage schemes (storage by rows and by columns) and investigate partial pivoting both by rows and by columns, yielding four factorization algorithms. The goal is to determine which of these four algorithms admit the most efficient parallel implementation. We analyze factors such as load distribution, pivoting cost, and potential for pipelining. We conclude that, in the absence of loop unrolling, LU factorization with partial pivoting is most efficient when pipelining is used to mask the cost of pivoting. The two schemes that can be pipelined are pivoting by interchanging rows when the coefficient matrix is distributed to the processors by columns, and pivoting by interchanging columns when the matrix is distributed to the processors by rows.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.127

**MODELING OF COMPLEX MELTING
AND SOLIDIFICATION BEHAVIOR
IN LASER-IRRADIATED MATERIALS
(A DESCRIPTION AND USERS' GUIDE
TO THE LASER8 COMPUTER PROGRAM)**

G. A. Geist R. F. Wood*

(Abstract of ORNL-6242, November 1985)

The conceptual foundation of a computational model and a computer program based on it have been developed for treating various aspects of the complex melting and solidification behavior observed in pulsed laser-irradiated materials. A particularly important feature of the modeling is the capability of allowing melting and solidification to occur at temperatures other than the thermodynamic phase change temperatures. As a result, interfacial undercooling and overheating can be introduced and various types of nucleation events can be simulated. Calculations on silicon with the model have shown a wide variety of behavior, including the formation and propagation of multiple phase fronts. Although originally developed as a tool for studying certain problems arising in the field of laser annealing of semiconductors, the program should be useful in treating many types of systems in which phase changes and nucleation phenomena play important roles.

This report describes the underlying physical and mathematical ideas and the basic relations used in LASER8. It also provides enough specific and detailed information on the program to serve as a guide for its use; a listing of one version of the program is given as an appendix.

Research sponsored by U.S. DOE Division of Materials Sciences.

*Solid State Division.

1.128

**GAUSSIAN ELIMINATION
WITH PARTIAL PIVOTING
AND LOAD BALANCING ON
A MULTIPROCESSOR**

A. George E. Chu*

(Abstract of ORNL/TM-10323, March 1987; also International Conference of Vector and Parallel Computing, Loeu, Norway, June 2-6, 1986)

A row-oriented implementation of Gaussian elimination with partial pivoting on a local-memory multiprocessor is described. In the absence of pivoting, the initial data loading of the node processors leads to a balanced computation. However, if interchanges occur, the computational loads on the processors may become unbalanced, leading to inefficiency. A simple load balancing scheme is described which is inexpensive and which maintains computational balance in the presence of pivoting. Using some reasonable assumptions about the probability of pivoting occurring, an analysis of the communication costs of the algorithm is developed, along with an analysis of the computation performed in each node processor. This model is then used to derive the expected speed-up of the algorithm. Finally, experiments using an Intel iPSC hypercube are presented in order to demonstrate the extent to which the analytical model predicts the performance.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research, by U.S. Air Force Office of Scientific Research, and by Canadian Natural Sciences and Engineering Research Council.

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1.129

SPARSE CHOLESKY FACTORIZATION ON A LOCAL-MEMORY MULTIPROCESSOR

A. George M. T. Heath
J. Liu* E. Ng

(Abstract of ORNL/TM-9962, April 1986; also *SIAM J. Sci. Stat. Comp.* (in press); also paper presented at the Impact of Supercomputing on Air Force R&D Meeting, Elgin Air Force Base, FL, November 3-5, 1986)

This article deals with the problem of factoring a large sparse positive definite matrix on a multiprocessor system. The processors are assumed to have substantial local memory but no globally shared memory. They communicate among themselves and with a host processor through message passing. Our primary interest is in designing an algorithm which exploits parallelism, rather than in exploiting features of the underlying topology of the hardware. However, part of our study is aimed at determining, for certain sparse matrix problems, whether hardware based on the binary hypercube topology adequately supports the communication requirements for such problems. Numerical results from experiments running on a multiprocessor simulator are included.

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1.130

SYMBOLIC CHOLESKY FACTORIZATION ON A LOCAL-MEMORY MULTIPROCESSOR

A. George M. T. Heath
E. Ng J. Liu*

[Abstract of *Parallel Computing* 5(1&2), 85 (1987)]

We present a parallel algorithm for symbolic Cholesky factorization of sparse symmetric matrices. The symbolic factorization algorithm complements a parallel numeric factorization algorithm published earlier. The implementation

is designed for a message-passing, distributed-memory multiprocessor. In addition to discussing the basic algorithm and data structures required, we also present two significant enhancements that improve performance. Empirical test results obtained on an Intel iPSC hypercube are given.

Research sponsored by U.S. DOE Computational Mathematics Project.

*York University, Downsview, Ontario, Canada.

1.131

SOLUTION OF SPARSE POSITIVE DEFINITE SYSTEMS ON A SHARED-MEMORY MULTIPROCESSOR

A. George M. T. Heath
E. Ng J. Liu*

[Abstract of ORNL/TM-10260, January 1987; also *Int. J. Parallel Programming* 13(4), 309 (1986)]

Algorithms and software for performing sparse Cholesky decomposition and using the Cholesky factors in the solution of sparse symmetric positive definite systems on serial computers have reached a high state of development. In this paper we present algorithms for performing these two phases on a shared-memory multiprocessor computer, along with some numerical experiments demonstrating their performance on a Sequent Balance 8000 system.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research, by U.S. Air Force Office of Scientific Research, and by Canadian Natural Sciences and Engineering Research Council.

*York University, Downsview, Ontario, Canada.

1.132

HOUSEHOLDER REFLECTIONS VERSUS GIVENS ROTATIONS IN SPARSE ORTHOGONAL DECOMPOSITION

A. George J. Liu*

[Abstract of *Linear Algebra and Its Applications* 88/89, 223 (1987)]

It has been generally assumed that the use of Givens rotations provides significant advantages over the use of Householder transformations for

the orthogonal decomposition of sparse matrices. It is also generally acknowledged that the opposite is true for dense matrices. In this paper, a way of applying Householder reflections is described which is competitive with or superior to the use of Givens rotations for sparse orthogonal decomposition. In other words, the advantage of Householder over Givens for dense matrices can carry over to the sparse case, provided that the implementation of the Householder scheme is done in a certain way. The approach relies heavily on the idea of general row merge trees developed by Liu. Results of numerical experiments are provided which demonstrate the advantages of the new scheme. The method also appears to be attractive for use on vector computers.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*York University, Downsview, Ontario, Canada.

1.133

THE EVOLUTION OF THE MINIMUM DEGREE ORDERING ALGORITHM

A. George J. Liu*

[Abstract of ORNL/TM-10452, May 1987; also *SIAM Review* (in press)]

Over the past fifteen years, the implementation of the minimum degree algorithm has received much study, and many important enhancements have been made to it. In this article, we describe these various enhancements, trace their historical development, and provide some experiments showing how very effective they are in improving the execution time of the algorithm. We also present a shortcoming that exists in all of the widely used implementations of the algorithm, namely, that the quality of the ordering provided by the implementations is surprisingly sensitive to the initial ordering. For example, changing the input ordering can lead to an increase (or decrease) of as much as a factor of three in the cost of the subsequent numerical factorization. This sensitivity is caused by the lack of an effective tie-breaking strategy, and our

experiments illustrate the importance of developing such a strategy.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research, by Natural Sciences and Engineering Research Council of Canada, by U.S. Air Force Office of Scientific Research, and by Science Alliance.

*York University, North York, Ontario, Canada.

1.134

COMMUNICATION REDUCTION IN PARALLEL SPARSE CHOLESKY FACTORIZATION ON A HYPERCUBE

A. George J. Liu*
E. Ng

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 576 (1987)]

We consider the problem of reducing data traffic among processor nodes in the parallel factorization of a sparse matrix on a hypercube multiprocessor. A task assignment strategy based on the structure of an elimination tree is presented. It may be viewed as a subtree-to-subcube assignment. This algorithm is aimed at achieving load balancing among the processors and also reducing the amount of processor-to-processor data communication. Some experimental results on the performance of this scheme will be presented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*York University, Downsview, Ontario, Canada.

1.135

ON THE COMPLEXITY OF SPARSE QR AND LU FACTORIZATION OF FINITE ELEMENT MATRICES

A. George E. Ng

[Abstract of *SIAM J. Sci. Stat. Comp* (in press)]

Let A be an $n \times n$ sparse nonsingular matrix derived from a two-dimensional finite element mesh. If the matrix is symmetric and positive definite, and a nested dissection ordering is used,

then the Cholesky factorization of A can be computed using $O(n^{3/2})$ arithmetic operations, and the number of nonzeros in the Cholesky factor is $O(n \log n)$. In this article we show that the same complexity bounds can be attained when A has the same structure but is nonsymmetric and indefinite, and either Gaussian elimination with partial pivoting or orthogonal factorization is applied. Numerical experiments for a sequence of irregular mesh problems are provided.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and U.S. Air Force Office of Scientific Research.

1.136

COMPUTING A SPARSE BASIS FOR THE NULL SPACE

J. R. Gilbert* M. T. Heath

[Abstract of *SIAM J. Alg. Disc. Meth.* 8(3), 446 (1987)]

We present algorithms for computing a sparse basis for the null space of a sparse underdetermined matrix. We describe several possible computational strategies, both combinatorial and noncombinatorial in nature, and we compare their effectiveness for several test problems.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Cornell University, Ithaca, NY.

1.137

HYPERCUBE APPLICATIONS AT ORNL

M. T. Heath

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; *Proc. SIAM Philadelphia*, p. 395 (1987)]

In order to help determine the potential viability of hypercube multiprocessor architectures for use on a broad spectrum of applications that arise, Oak Ridge National Laboratory has sponsored for the past year several pilot applications projects for implementation on one of the laboratory's two hypercubes. These projects included problems in computer vision, molecular

dynamics, density functional theory, nonlinear magnetohydrodynamics, fracture analysis, cascade simulation, and containment transport. In this talk we overview the successes and shortcomings encountered in porting existing codes and in developing new parallel algorithms for these applications. Time permitting, brief mention will also be made of other hypercube research at ORNL, including robotics applications and matrix computations.

Research sponsored by Applied Mathematical Sciences, U.S. DOE Office of Energy Research.

1.138

PARALLEL COMPUTING CONFERENCE FEATURES HYPERCUBES

M. T. Heath

[Abstract of *SIAM News* 20(3), 12 (1987)]

This newsletter article reviews the rationale for and events taking place at the Second Conference on Hypercube Multiprocessors held in Knoxville, Tennessee. Highlights of the technical program are noted.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.139

PARALLEL MATRIX COMPUTATIONS ON HYPERCUBES

M. T. Heath

(Abstract of oral presentation to be presented at the 35th SIAM Anniversary Meeting, Denver, CO, October 12-15, 1987)

In this talk we survey recent results in matrix computation on distributed-memory, message-passing multiprocessors, particularly hypercubes. Primary emphasis is on matrix factorization and the solution of triangular systems. Both dense and sparse matrices are considered. Computational results obtained on several different hypercubes are presented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.140

PARALLEL SOLUTION OF TRIANGULAR SYSTEMS ON DISTRIBUTED-MEMORY MULTIPROCESSORS

M. T. Heath

(Abstract of oral presentation to be presented at the Gatlinburg X International Conference on Numerical Algebra, Fairfield Glade, TN, October 19-23, 1987)

The solution of triangular systems of linear equations on conventional serial computers is usually considered an essentially trivial computation compared to matrix factorization. On parallel computers, especially those with distributed memory, the necessary communication among processors causes the relative costs of matrix factorization and triangular solution to be quite different from the serial case, with good efficiency being much more difficult to attain for triangular solution. In this paper we present new parallel wavefront algorithms for solving triangular systems partitioned by rows or by columns on distributed-memory multiprocessors. Performance of the new algorithms is analyzed theoretically and compared both theoretically and empirically with previous algorithms using implementations on commercial hypercubes.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.141

SPARSE MATRIX COMPUTATIONS ON A HYPERCUBE MULTIPROCESSOR

M. T. Heath

(Abstract of oral presentation given at the Army Research Office Workshop on Parallel Processing and Medium Scale Multiprocessors, Stanford University, Stanford, CA, January 6-8, 1986)

This talk deals with the problem of factoring a large sparse positive definite matrix on a multiprocessor system. The processors are assumed to have substantial local memory, but no globally shared memory, and to communicate among themselves with a host processor through message

passing. Our primary interest is in designing an algorithm which exploits parallelism, rather than in exploiting features of the underlying topology of the hardware. However, part of our study is aimed at determining, for certain sparse matrix problems, whether hardware based on the binary hypercube topology adequately supports the communication requirements for such problems. Numerical results from experiments run on a multiprocessor simulator are included, as well as results from a 64-node Intel iPSC d6 hypercube.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and by Air Force Office of Scientific Research.

1.142

PARALLEL SOLUTION OF TRIANGULAR SYSTEMS ON DISTRIBUTED-MEMORY MULTIPROCESSORS

M. T. Heath C. H. Romine

[Abstract of ORNL/TM-10384, March 1987; also *SIAM J. Sci. Stat. Comp.* (in press)]

Several parallel algorithms are presented for solving triangular systems of linear equations on distributed-memory multiprocessors. New wavefront algorithms are developed for both row-oriented and column-oriented matrix storage. Performance of the new algorithms and several previously proposed algorithms is analyzed theoretically and illustrated empirically using implementations on commercially available hypercube multiprocessors.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.143

DIRECT SOLUTION OF SPARSE LINEAR SYSTEMS ON MULTIPROCESSORS

E. Ng

(Abstract of oral presentation to be presented at the 35th SIAM Anniversary Meeting, Denver, CO, October 12-15, 1987)

In the direct solution of a linear system, the coefficient matrix is first decomposed into triangular factors. At each stage of the decomposition, the computation typically involves two tasks: modifying a column by previous columns (cmod) and dividing the column by the pivot element when the modifications are complete (cdiv). There is inherent parallelism in the decomposition. After a cdiv is performed, the column is used to modify the remaining columns. The cmod's may be carried out concurrently if there are multiple processors available. There may be additional parallelism if the matrix is sparse, since each column is modified by just a few previous columns. Thus some of the cdiv's may be carried out simultaneously. In this talk we survey some of the algorithms we have developed for solving sparse linear systems on multiprocessors.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.144

DIRECT SOLUTION OF SPARSE NONSYMMETRIC LINEAR SYSTEMS

E. Ng

(Abstract of oral presentation to be presented at the Gatlinburg X International Conference on Numerical Algebra, Fairfield Glade, TN, October 19-23, 1987)

Let A be a sparse nonsymmetric (and nonsingular) matrix and consider the problem of solving the linear system $Ax=b$. The solution process typically involves computing a triangular factorization of A using Gaussian elimination with row interchanges. In this talk a technique for predicting the structures of the triangular factors is described. Knowing the structures of the triangular factors allows a compact data structure

to be set up for storing the numerical values during the numerical factorization. An algorithm for computing the decomposition using the fixed storage structure is presented. Parallel implementation of the algorithm on shared-memory multiprocessor systems is also described.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

I.145

RECENT DEVELOPMENTS IN THE DIRECT SOLUTION OF SPARSE NONSYMMETRIC LINEAR SYSTEMS

E. Ng

(Abstract of oral presentation presented to the Department of Computer Science, University of Tennessee, Knoxville, TN, November 5, 1986; and to be presented to the Department of Computer Science, Vanderbilt University, Nashville, TN, October 1, 1987; to the Department of Computer Science, University of Tulsa, Tulsa, OK, November 23, 1987; and to the Department of Mathematics, Oklahoma State University, Oklahoma City, OK, November 24, 1987)

Let A be an $n \times n$ sparse nonsymmetric (nonsingular) matrix and consider the problem of solving the linear system $Ax=b$. The solution process typically involves computing a triangular factorization of A (for example, using Gaussian elimination with partial pivoting). Existing software packages for computing such a decomposition often make use of dynamic storage allocations. Thus, the storage requirements are unpredictable. Furthermore, experience has shown that the overhead in storage and execution times may sometimes be large. In the talk, we survey some recent attempts in implementing sparse Gaussian elimination with partial pivoting using fixed storage schemes. Numerical experiments comparing the static and dynamic implementations will be provided. Some outstanding problems associated with the static implementations will also be discussed.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.146

SOLUTION OF SPARSE POSITIVE DEFINITE SYSTEMS ON A SHARED-MEMORY MULTIPROCESSOR

E. Ng

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

Algorithms and software for performing sparse Cholesky decomposition and using the Cholesky factors in the solution of sparse symmetric positive definite systems on serial computers have reached a high state of development. In this paper we present algorithms for performing these two phases on a shared-memory multiprocessor computer, along with some numerical experiments demonstrating their performance on a Sequent Balance 8000 system.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.147

EXPERIMENTS WITH METHOD OF LINES SOLVERS ON A SHARED MEMORY PARALLEL COMPUTER

E. Ng S. Thompson
P. G. Tuttle*

(Abstract of paper presented at the Sixth International Association for Mathematics and Computers in Simulation Conference on Computer Methods for Partial Differential Equations, Lehigh University, Bethlehem, PA, June 23-26, 1987; Proc. p. 161 (1987))

This paper presents the results of experiments associated with adapting ordinary differential equation (ode) solvers to a shared memory parallel computer. The method of lines is applied to a model stiff fluid flow problem to provide a system of odes. A simplified code for the solution of this problem is discussed. Portions of the code amenable to parallel solution are identified. In particular, formation of the Jacobian matrix and the linear algebra required in the solution of the corrector equations are identified as natural candidates for parallel implementation. Timing

results are given for the simplified code that demonstrate the improvements in execution times for multiple processors. The implementation of these ideas in the well-known LSODE solver is discussed and timing results are given for the parallel version. The results suggest that for moderate sized and large systems of equations, speedups in computer execution time that are nearly linear in the number of processors are possible.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*TRW Defense Systems Division, Fairfax, VA.

1.148

THE *ijk* FORMS OF FACTORIZATION METHODS II. PARALLEL COMPUTERS

J. M. Ortega* C. H. Romine

[Abstract of *Parallel Computing* (in press)]

In this paper we consider the solution on parallel computers of a system of linear equations $Ax=b$, where A is an $n \times n$ matrix. We restrict our attention to two common matrix factorization algorithms, LU factorization and Cholesky decomposition when the matrix is symmetric and positive definite.

In Part I of the current work, we expanded the " ijk " analysis of LU factorization for vector computers given in Dongarra *et al.* to include Cholesky factorization. The present paper uses the same " ijk " framework to analyze both LU and Cholesky factorization, but now extended to local-memory multiprocessor computers, including the case where each processor may have vector capabilities.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research and National Aeronautics and Space Administration.

*University of Virginia, Charlottesville, VA.

1.149

COLUMNS VS. ROWS FOR GAUSSIAN ELIMINATION WITH PIVOTING ON A HYPERCUBE MULTIPROCESSOR

C. H. Romine

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

We examine the effect that the storage scheme for the coefficient matrix has on the efficiency of parallel Gaussian elimination with partial pivoting. The storage schemes considered are interleaving by rows and by columns. Results from an analytical model suggest that the serial pivot search encountered when using column storage may become a significant term in the expression for execution time. Implementation of the two algorithms on the Intel iPSC Hypercube confirms that using row storage, which allows the pivot search to be parallelized, yields a more efficient algorithm.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.150

PARALLEL SOLUTION OF TRIANGULAR SYSTEMS ON A HYPERCUBE

C. H. Romine

(Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 552 (1987))

It has been suggested by several authors that the solution of an $n \times n$ triangular system in which the coefficient matrix is stored by columns is difficult to parallelize, requiring the full serial execution time. We exhibit a parallel implementation of the textbook inner product algorithm which is shown to be highly efficient for large n . Results on an Intel iPSC hypercube confirm that it is nearly as efficient as the usual column-sweep algorithm applied to a system stored by rows.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.151

LU FACTORIZATION ALGORITHMS ON DISTRIBUTED-MEMORY MULTIPROCESSOR ARCHITECTURES

C. H. Romine G. A. Geist

(Abstract of oral presentation to be presented at the Gatlinburg X International Conference on Numerical Algebra, Fairfield Glade, TN, October 19-23, 1987)

We consider the effect that the data storage scheme has on the efficiency of LU factorization with pivoting on a distributed-memory multiprocessor. Our presentation will focus on the hypercube architecture, but most of our results are applicable to distributed-memory architectures generally. We restrict our attention to two commonly used storage schemes (storage by rows and by columns) and pivoting by interchanging rows. (Factorization with pivoting by columns can be regarded as factoring the transpose of the coefficient matrix with pivoting by rows.) The choice of storage scheme affects the influence of factors such as load distribution, pivoting cost, potential for pipelining, and loop unrolling. The goal is to determine the most efficient parallel implementation of LU factorization. Comparisons are made based upon the execution times obtained from an Intel iPSC hypercube.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.152

PERFORMANCE MODELING OF THREE ITERATIVE METHODS ON A HYPERCUBE

C. Vaughan

(Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 692 (1987))

A hypercube implementation of three iterative methods — SOR, conjugate gradient, and m -step SSOR preconditioned conjugate gradient — will be presented for both a finite element and a finite difference problem. Results from the Intel hypercube indicate that large sized problems are neces-

sary to get good efficiency. In order to understand these results a predictive model for each of the methods, which breaks the run time up into time spent computing and communicating, has been developed and will also be presented.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.153

MATHEMATICAL SCIENCES RESEARCH AT THE OAK RIDGE NATIONAL LABORATORY

R. C. Ward

[Abstract of *ORNL Review* 19(3), 119 (1986); also oral presentation given at a Mathematics Department Seminar, Northern Illinois University, DeKalb, IL, April 24, 1987]

This article presentation discusses the research, consulting, and collaboration activities of the Mathematical Sciences Section of the Engineering Physics and Mathematics Division of the Oak Ridge National Laboratory. A few examples of the technical problems faced by the section's mathematicians, statisticians, and computer scientists are discussed. The computer science research program at ORNL is discussed in slightly more detail along with a description of the research computer facilities available to the section.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.154

SOLVING SCIENTIFIC PROBLEMS ON HYPERCUBE PARALLEL COMPUTERS

R. C. Ward

[Abstract of paper presented at the Invitational Forum on the Supercomputing Decision for Cost-Effective Scientific Computations, George Mason University, Fairfax, VA, May 15, 1986; Proc. p. 176 (1986)]

The presentation discusses the research activities on hypercube parallel computers at Oak Ridge National Laboratory and assesses the potential of hypercubes for solving large scale scientific computational problems. Items discussed are the reasons ORNL purchased two hypercube computers, the results of our basic research on matrix computations, the status of the seven applications projects being "converted" to run on the hypercube, the suggested steps for programming parallel computers, and the advantages and problem areas of the hypercube architecture for solving today's scientific problems.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

1.155

DENSITY FUNCTIONAL THEORY AND PARALLEL PROCESSING

**R. Ward* G. A. Gelst
W. F. Butler†**

(Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 473 (1987))

We demonstrate a method for obtaining the ground state energies and charge densities of a system of atoms described within density functional theory using simulated annealing on a parallel computer.

Research sponsored by the Exploratory Studies Program.

*Computing and Telecommunications Division.

†Metal and Ceramics Division.

Section 2

NUCLEAR DATA MEASUREMENT AND EVALUATION AT THE OAK RIDGE ELECTRON LINEAR ACCELERATOR (ORELA)

2.0. INTRODUCTION

R. W. Peelle

Our Section is playing an important role in the work to assemble within the next year the sixth version of the national ENDF/B reference file. This evaluated neutron cross section file is derived from experiment and theory to provide all the input data needed to compute nuclear system behavior. We are trying to include what has been learned in the several years since the previous ENDF/B release, and for important materials even to obtain new data to affect the file content. Much of our work is concentrated on the nuclides of structural and fuel materials because system performance parameters have high sensitivity to their cross sections. One can already see that for many nuclides even the ENDF/B-VI file will not fully meet future data needs or exhaust our ability to develop improvements.

There is an immediate demand for evaluated cross sections for fusion reactor materials to use in the international fusion reactor project ITER. This file should be available in the next year, be composed of quality data to encourage project success, and reflect contributions from the participating countries. We expect that some of the new complete evaluations by our group will be incorporated into this international file.

Obtaining accurate cross section values for the most demanding cases challenges established methods for reduction and analysis of experimental data. As goals have been refined and as computing capabilities have increased, traditional techniques have been improved or replaced. Most world-wide comparisons of methods and results are reassuring, but those for the parameters of the lowest-energy neutron resonance in iron-56 exposed sharp conflicts. We diagnose and correct such discrepancies to increase the quality of future results. International efforts to improve data quality have become more effective during recent years, and help to assure the future relevance of the present nuclear data program.

High resolution transmission measurements are a mainstay of the experimental work because of their fundamental importance and absolute nature; a difficult series of such experiments on U-238 has been initiated. A new set of high-resolution fission data is being acquired because work here to extend the parameterized resolved resonance ranges for the important fissile nuclides is limited by the world data base. Neutron scattering equipment is now being redeployed for application to the resonance regions of iron-56 and perhaps other nuclides of structural materials.

A share of our effort, and most of our visitors, perform neutron capture studies motivated by astrophysical interest in the diverse patterns of abundance of the chemical elements. Capture measurements are also motivated by the fission product poison effect in fast reactors and occasionally by data needs of those who study production of useful radioisotopes. We are developing a photon multiplicity detector system to allow better measurements of neutron capture for fissile nuclides.

The experiment program is now fully developed for measurement of excitation functions for neutrons up to about 40 MeV for the important gamma-ray transitions. Data have already been acquired for the boron isotopes and for a series of structural materials. These data on the inelastic scattering, (n,p) , etc. reactions provide needed constraints on reaction theory in the energy region important to fusion energy.

The ORELA itself continues to be reliable and powerful. For the shortest pulses used, the best performance ever (4 gigawatts of electron beam in 3 ns pulses) was achieved this year, and we typically operate above the original machine specifications over the whole range of pulse widths. Our

greatest long-term maintenance problem seems to have been overcome by an innovation in electron gun fabrication. The same high-performance unit has been in use for over a year, and there has been little buildup of grid emission current.

We look forward to playing a strong role in the completion of the ENDF/B-VI reference file, to upgrading our experimental and data reduction techniques, and to using our capabilities to develop cross sections of the high quality needed to meet both applied and basic goals.

Experimental Results

2.1

GAMMA-RAY PRODUCTION CROSS SECTIONS FOR 0.9 TO 20 MeV NEUTRON INTERACTIONS WITH ^{10}B

R. L. Bywater, Jr.*

(Abstract of ORNL/TM-10191, September 1986)

Gamma-ray spectral data previously obtained at the 20-meter station of the Oak Ridge Electron Linear Accelerator flight-path 8 were studied to determine cross sections for 0.9- to 20-MeV neutron interactions with ^{10}B . Data reduction techniques, including those for determination of incident neutron fluences as well as those to compensate for Doppler-broadened gamma-ray-detection responses, are given in some detail in this report.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Nebraska Wesleyan College, Lincoln, NE.

2.2

RESONANCE NEUTRON CAPTURE BY $^{20,22}\text{Ne}$ IN STELLAR ENVIRONMENTS

R. R. Winters* R. L. Macklin

(Abstract of *Astrophysical J.* (in press))

We have measured the neutron capture cross sections over the neutron energy range 2.5 to 200 keV of $^{20,22}\text{Ne}$ at the Oak Ridge Electron Linear Accelerator (ORELA) using enriched samples at high pressures. The cross sections, averaged using a Maxwell-Boltzmann distribution weighting function for a range of temperatures thought to be appropriate for the sites of *s*-process stellar nucleosynthesis, are small. For example, the Maxwellian-averaged $^{22}\text{Ne}(n, \gamma)$ cross section for $kT = 30$ keV derived from the present work is smaller than 0.27 mb. This result increases the calculated net neutron production from ^{22}Ne by reducing the importance of $^{22}\text{Ne}(n, \gamma)$ as a neu-

tron poison in *s*-process calculations. The number of neutrons per ^{56}Fe seed available for *s*-process stellar nucleosynthesis appears sufficient to account for the observed abundances of the heavier elements.

Research sponsored by U.S. Department of Energy and Denison University.

*Denison University, Granville, OH.

2.3

RESONANCE STRUCTURE OF $^{33}\text{S} + n$ FROM TRANSMISSION MEASUREMENTS

G. P. Coddens* N. Salah†
J. A. Harvey N. W. Hill‡
N. M. Larson§

(Abstract of *Nucl. Phys. A469*, 480 (1987))

The neutron total cross section for ^{33}S has been determined for energies from 10 keV up to 2 MeV at the Oak Ridge Electron Linear Accelerator (ORELA) by a time-of-flight (TOF) transmission experiment. By combining these results with (n, α) data obtained at the Geel Electron Linear Accelerator (GELINA), resonance parameters (E_λ , J^π , and Γ_n) have been determined up to 270 keV. Neutron strength functions for *s*- and *p*-wave resonances were derived. The *p*-wave strength function is much larger than for other nuclides in this mass region (^{30}Si , ^{32}S , and ^{34}S). This is discussed within the framework of the spherical optical model.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*University of Antwerp, Belgium.

†Minia University, El Minia, Egypt.

‡Instrumentation and Controls Division.

§Computing and Telecommunications Division.

2.4

**NUCLEAR STRUCTURE OF ^{49}Ca
ABOVE 5 MeV EXCITATION
FROM $n + ^{48}\text{Ca}$ AND ASTROPHYSICS
FOR 30 keV NEUTRONS**

R. F. Carlson^{*} J. A. Harvey
R. L. Macklin C. H. Johnson[†]
B. Castel[‡]

[Abstract of *Nucl. Phys. A465*, 274 (1987)]

The level structure of ^{49}Ca has been investigated above the neutron separation energy by measurements of the total and capture cross sections for neutron energies up to 2 MeV. Transmission data were obtained for two $^{48}\text{CaCO}_3$ samples enriched to 96% in ^{48}Ca and were analyzed in the R-matrix formalism for neutron energies up to 2 MeV. An upper limit of 0.07×10^{-4} was placed upon the s -wave strength function ($\langle \Gamma_n^0 \rangle / D$) and an optical model real potential was deduced from the low energy total cross section. Approximately 45% of the $2d_{5/2}$ single particle strength is observed in the region below 2 MeV neutron energy. Model configurations based on continuum shell model calculations which describe this strength and its distribution are presented. Combined low energy results are used to obtain the Maxwellian averaged capture cross section and the result is discussed in relation to the nucleosynthesis of ^{49}Ca and the anomalous abundances observed in an inclusion of the Allende meteorite.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^{*}Middle Tennessee State University, Murfreesboro, TN.

[†]Physics Division.

[‡]Queen's University, Kingston, Ontario, Canada.

2.5

**GAMMA-RAY DECAY OF LEVELS
IN ^{53}Cr**

J. K. Dickens D. C. Larson

(Abstract of ORNL-6418, October 1987)

Gamma-ray decay of levels in the stable isotope ^{53}Cr has been studied using $^{53}\text{Cr}(n, n'\gamma)$

reactions for incident neutron energies between threshold and 10 MeV. Of the 65 gamma rays or gamma-ray groups observed for neutron interactions with ^{53}Cr , 50 have been placed or tentatively placed among 34 levels in ^{53}Cr up to an excitation energy of 4.36 MeV. Deduced branching ratios are in reasonable agreement with previous measurements except for decay of the $E_x = 1537$ -keV level. For the decay of the $E_x = 1537$ -keV level we are unable to explain variations in the branching ratios of the transition gamma rays as a function of incident neutron energy within the framework of the presently known level structure of ^{53}Cr and suggest the possibility of a second energy level at $E_x = 1537$ keV.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.6

**A SELF-CALIBRATED
NEUTRON CAPTURE MEASUREMENT
OF THE 1.15-keV
RESONANCE OF IRON**

R. L. Macklin

[Abstract of *Nucl. Sci. Eng.* 95, 200 (1987)]

A measurement with thick and thin iron samples showed that $\Gamma_n \Gamma_\gamma / T = 55.5 \pm 0.6$ meV and $\Gamma_n = 61.5 \pm 0.7$ meV for the 1.15-keV iron resonance.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.7

**MAXWELLIAN-AVERAGED NEUTRON
CAPTURE CROSS SECTIONS
FOR ^{99}Tc AND $^{95-98}\text{Mo}$**

R. R. Winters^{*} R. L. Macklin

[Abstract of *Astrophysical J.* 313, 808 (1987)]

This paper presents the Maxwellian-averaged neutron capture cross sections for ^{99}Tc and $^{95,96,97,98}\text{Mo}$. An extensive temperature range (5-100 keV) is included to encompass the model calculations for on-going s -process nucleosynthesis

in red giant stars where technetium has been observed. At $T = 30$ keV, the most often chosen temperature for the s -process, we find 782 ± 39 mbarn for ^{99}Tc , 292 ± 2 mbarn for ^{95}Mo , 112 ± 6 mbarn for ^{96}Mo , 339 ± 2 mbarn for ^{97}Mo , and 99 ± 5 mbarn for ^{98}Mo . These results are used to estimate the duration of the third dredge-up phase for two thermally pulsing asymptotic giant branch stars for which the technetium-to-molybdenum abundances have been measured.

Research sponsored by U.S. DOE Division of Nuclear Sciences and Office of Basic Energy Sciences.

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2.8

NEUTRON CAPTURE AND TOTAL CROSS SECTIONS OF $^{144}\text{Sm} + n$

R. L. Macklin J. A. Harvey
N. W. Hill* G. L. Tweed†

(Abstract of paper presented at the 1986 Fall Divisional Meeting of the American Physical Society, Vancouver, B.C., Canada, October 9-11, 1986)

The neutron capture and total cross sections of $^{144}\text{Sm} + n$ have been measured at the Oak Ridge Electron Linear Accelerator for neutron energies from 0.5 eV to 500 keV using a sample enriched to 96.5%. The capture data are analyzed to obtain parameters for the individual resonances up to 12 keV and average cross sections above this energy. Resonance neutron capture by ^{144}Sm is of interest for nucleosynthesis in stars and is of current interest for the production of ^{145}Pm . The neutron widths of the resonances and the l -value assignments for s - and p -wave resonances are obtained from the transmission data. The lightest and least abundant (3.1%) isotope of Sm is ^{144}Sm , but it is the heaviest of seven stable isotones with a closed shell of 82 neutrons. The average s -wave level spacing is only about 250 eV, considerably smaller than those of the even- Z stable isotones with $N = 82$ starting with Xe_{136}^{136} , and the s -wave strength function is considerably larger.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

†University of Tennessee, Knoxville, TN.

2.9

NEUTRON CAPTURE CROSS SECTIONS OF ^{151}Eu AND ^{153}Eu FROM 3 TO 2200 keV

R. L. Macklin P. G. Young*

[Abstract of *Nucl. Sci. Eng.* 95, 189 (1987)]

Neutron capture by enriched stable isotopes of europium was measured as a function of energy by time of flight at the Oak Ridge Electron Linear Accelerator. Deformed optical model and reaction theory calculations using the published total cross section for natural europium and low energy resonance parameters were made to compare with the present data. Maxwellian average capture at $kT=30$ keV was calculated as (3.40 ± 0.14) b for ^{151}Eu and (2.48 ± 0.10) b for ^{153}Eu .

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Los Alamos National Laboratory, Los Alamos, NM.

2.10

NEUTRON CAPTURE RESONANCES OF ^{152}Gd AND ^{154}Gd

R. L. Macklin

[Abstract of *Nucl. Sci. Eng.* 95, 304 (1987)]

Neutron resonance parameters were found for ^{152}Gd up to 2700 eV. An average s -wave spacing $D_0 = (17.4 \pm 1.0)$ eV and radiation width (58.6 ± 3.0) eV were found. The resonance contribution to the capture integral was found as (397 ± 32) barns, exclusive of a $1/v$ term. Resonance parameters for ^{154}Gd were extended from 490 to 2760 eV.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.11

A STOPWATCH FOR THE TIME DURATION OF THE s -PROCESS NEUTRON IRRADIATIONS

H. Beer^{*} R. L. Macklin

(Abstract of paper presented at the German Physical Society Nuclear Physics Meeting, Groningen City, Holland, March 23-27, 1987)

The neutron capture cross sections of $^{152,154,155,157}\text{Gd}$ have been measured at the Oak Ridge Electron Linear Accelerator (ORELA) in the energy range 2.6 keV to 500 keV using the time-of-flight technique and a pair of C_4F_6 liquid scintillation counters for the detection of the capture events via the prompt emitted γ -ray cascades. The $^{152,154}\text{Gd}$ isotopes are of special interest in s -process nucleosynthesis, because they are situated in a branching of the synthesis path sensitive to the time structure of the neutron irradiations. In the analysis it was found that the neutron bursts of the s -process must be larger or equal than 3 yr to be consistent with the solar abundance pattern of $^{152,154}\text{Gd}$.

Research sponsored by Karlsruhe, FRG.

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2.12

NEUTRON CAPTURE CROSS SECTIONS OF RHENIUM FROM 3 TO 1900 keV

R. L. Macklin P. G. Young^{*}

[Abstract of *Nucl. Sci. Eng.* 97, 239 (1987)]

The neutron capture cross section of elemental rhenium was measured to neutron energies between 3 and 1900 keV at the Oak Ridge Electron Linear Accelerator time-of-flight facility. A deformed optical model was used to analyze published neutron total cross sections for rhenium and low energy average resonance parameters for ^{185}Re and ^{187}Re . The optical model results were used with reaction theory to calculate radiative capture cross sections for comparison with the present experimental data.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^{*}Los Alamos National Laboratory, Los Alamos, NM.

2.13

THE $^{189}\text{Os}(n,\gamma)$ CROSS SECTION AND IMPLICATIONS FOR THE DURATION OF STELLAR NUCLEOSYNTHESIS

R. R. Winters^{*} R. L. Macklin
R. L. Hershberger[†]

[Abstract of *Astron. Astrophys.* 171, 9 (1987)]

This paper reports the results of a measurement of the $^{189}\text{Os}(n,\gamma)$ cross sections over the energy ranges 200 to 500 eV and 2.6 to 500 keV. We report resonance parameters for the lower energy region and these results yield an observed s -wave mean level spacing $D_0 = (3.4 \pm 0.2)$ eV, a neutron strength function $S_0 = (2.9 \pm 0.5) \times 10^{-4}$ and an average total radiation width $\langle\Gamma_\gamma\rangle = (83 \pm 5)$ meV. The averaged cross sections over the upper energy range provide constraints on the optical model potential and giant dipole resonance model used to represent the cross section. For astrophysical applications we report the 30-keV Maxwellian averaged cross section $\langle\sigma_\gamma\rangle = (1168 \pm 47)$ mb and use the ^{187}Re beta decay to estimate the duration of stellar nucleosynthesis as (11.0 ± 2.5) Gyr.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^{*}Denison University, Granville, OH.

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2.14

$^{189}\text{Os} + n$ s -WAVE MEAN LEVEL SPACINGS AND STRENGTH FUNCTIONS

R. F. Carlton^{*} R. R. Winters[†]
G. L. Tweed[‡] J. A. Harvey
N. W. Hill[§]

(Abstract of paper presented at the American Physical Society Meeting, Crystal City, VA, April 20-23, 1987; *Proc. Bull. Am. Phys. Soc.* 32(4), 1110 (1987))

The total neutron cross section has been measured for $^{189}\text{Os} + n$ over the incident neutron energy range 6 eV to 500 keV. R -matrix analysis of 45 s -wave resonances over the range 6-170 eV has been performed. The preliminary s -wave mean level spacings and strength function for the

16 resonances with $J=1$ are $\langle D \rangle = (10.6 \pm 1.4)$ eV and $S = (3.0 \pm 1.1) \times 10^{-4}$. For the 29 s -wave resonances with $J=2$ we find $\langle D \rangle = (5.7 \pm 0.6)$ eV and $S = (3.1 \pm 0.9) \times 10^{-4}$. The s -wave strength function (without regard to J) is $S = (3.1 \pm 0.7) \times 10^{-4}$. These results are of interest in determining the optical model potential (OMP) for the osmium mass region and in estimating the duration of galactic nucleosynthesis.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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2.15

SPHERICAL OPTICAL MODEL POTENTIAL FOR THE Re/Os STELLAR NUCLEOSYNTHESIS CHRONOMETER FROM s -WAVE NEUTRONS ON $^{186,187,188}\text{Os}$

R. R. Winters* R. F. Carlton†
J. A. Harvey N. W. Hill‡

[Abstract of *Phys. Rev. C* 34(3), 840 (1986)]

This paper reports resonance parameters and spherical optical model potentials obtained from the analyses of neutron transmission measurements for $^{186,188}\text{Os}$ over the incident neutron energy range 27 to 1000 eV and for ^{187}Os over the range 27 to 140 eV. Multilevel R-matrix analyses of 77 s -wave resonances yielded sets of resonance parameters ($E_\lambda, \Gamma_\lambda$) and the associated external (background) R-functions. The statistical properties of the resonance parameters, mean-level spacings, and strength functions are reported. The external R-functions and strength functions were used to determine spherical optical model potential (OMP) well depths, which in the case of ^{187}Os we find to be strongly dependent on the spin of the compound nucleus. These optical model well depths can be used to estimate the capture cross section of the first excited state in $^{187}\text{Os} + n$. Since this state is highly populated at stellar temperatures, the ratio of excited to ground-state capture cross sections is an impor-

tant parameter in using the s -process model of stellar nucleosynthesis to determine what fraction of the abundance of ^{187}Os should be ascribed to the radiogenic decay of ^{187}Re . That fraction determines, in part, the estimate of the duration Δ of stellar nucleosynthesis to be derived from ^{187}Re beta decay. A determination of Δ for the Re/Os chronometer based on our data leads to an age of the universe of $(17 \pm 3) \times 10^9$ y.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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‡Instrumentation and Controls Division.

2.16

HIGH RESOLUTION MEASUREMENT OF THE ^{238}U NEUTRON CAPTURE YIELD FOR INCIDENT NEUTRON ENERGIES BETWEEN 1 AND 100 keV

Roger L. Macklin* R. B. Perez
G. de Saussure R. W. Ingle†

[Abstract of *Trans. Am. Nucl. Soc.* 54, 344 (1987)]

High resolution neutron capture measurements were made on three metallic samples of ^{238}U , of areal densities $N = 0.0124, 0.0031$, and 0.0006 atoms/barn at the Oak Ridge Electron Linear Accelerator (ORELA) time-of-flight facility for incident neutron energies from 1 to 100 keV. Capture gamma rays were detected by a large liquid scintillator tank (ORELAST) located on a 150-m flight path. The shape of the incident neutron spectrum was determined by a 1-mm-thick ^6Li glass scintillation monitor placed upstream of the ORELAST. The energy resolution achieved in this measurement frequently resulted in doublets or multiple splittings of what had appeared to be single resonances in previous measurements. Enough structure is exhibited in the 15-keV region for use of resolved resonance methodologies. R-matrix analysis of the capture yield has been performed for several selected energy regions using the resonance analysis code OLSFIT. The present ^{238}U capture measurement, particularly when combined with

high resolution transmission results, will have significant impact in reactor design and neutron spectroscopy studies.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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2.17

HIGH RESOLUTION MEASUREMENT OF THE ^{238}U NEUTRON CAPTURE YIELD FOR INCIDENT NEUTRON ENERGIES FROM 1 keV TO 100 keV

Roger L. Macklin^a

(Abstract of Thesis for Master of Science Degree, University of Tennessee, Knoxville, TN, August 1987)

The purpose of this work is the precise determination of the ^{238}U capture yield (i.e., the probability of neutron absorption) as a function of neutron energy with the highest available neutron energy resolution. The motivation for the undertaking of such a complex and lengthy task arises from the central role played by the ^{238}U neutron capture process in the calculation of the neutron balance of both thermal reactors and fast breeder reactors. Requirements from the reactor design community for improved understanding and representation of the ^{238}U neutron capture led the Nuclear Energy Agency Nuclear Data Committee (NEANDC) to set up the ^{238}U Task Force to evaluate the available ^{238}U neutron capture data. This NEANDC task force recommended that a new high energy resolution measurement of the ^{238}U capture yield should be performed. With this added incentive, a cooperative program was initiated between the Oak Ridge National Laboratory and the University of Tennessee Nuclear Engineering Department to perform the present measurement using the Oak Ridge Electron Linear Accelerator (ORELA) facility.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^aUniversity of Tennessee, Knoxville, TN.

2.18

PARAMETERS OF THE 1.056-eV RESONANCE IN ^{240}Pu AND THE 2200 m/s NEUTRON TOTAL CROSS SECTIONS OF ^{235}U , ^{239}Pu , AND ^{240}Pu

**R. R. Spencer J. A. Harvey
N. W. Hill^a L. W. Weston**

[Abstract of Nucl. Sci. Eng. 96, 318 (1987)]

The Bayesian method was applied to the simultaneous fitting of neutron transmission measurements on five thin and two thick samples of ^{240}Pu to obtain the parameters of the very large resonance near 1 eV. The results of the analysis are $E_0 = 1.0564 \pm 0.0006$ eV, $\Gamma_\gamma = 30.3 \pm 0.3$ meV, and $\Gamma_n = 2.45 \pm 0.02$ meV. Some evidence in the data of a small deviation from the usual "weak binding" model for Doppler broadening of the theoretical resonance shape is presented. Transmission measurements on samples of ^{235}U , ^{239}Pu , and ^{240}Pu also were made over the thermal energy region and their neutron total cross sections were derived. Fits of the form $A/\sqrt{E} + B$ to the cross-section data in the interval from 0.02 to 0.03 eV resulted in the values 690 ± 5 , 1025 ± 6 , and 284 ± 2 b for the 2200 m/s total cross sections of ^{235}U , ^{239}Pu , and ^{240}Pu , respectively.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^aInstrumentation and Controls Division.

2.19

MEASUREMENTS OF THE ENERGY
DEPENDENCE OF PROMPT NEUTRON
EMISSION FROM ^{233}U , ^{235}U ,
AND ^{239}Pu FOR $E_n = 0.0005$
TO 10 MeV RELATIVE TO
EMISSION FROM SPONTANEOUS
FISSION OF ^{252}Cf

R. Gwin R. R. Spencer
R. W. Ingle*

[Abstract of *Nucl. Sci. Eng.* 94, 365 (1986)]

A series of experiments was performed to measure the dependence on the incident neutron energy of the average number of prompt neutrons emitted per fission from ^{233}U , ^{235}U , and ^{239}Pu relative to the average number of prompt neutrons emitted in spontaneous fission of ^{252}Cf . The incident neutron-energy range was 0.0005 to 10 MeV. A white neutron source was generated by the Oak Ridge Electron Linear Accelerator, and the energies of the neutrons incident on the fissile samples were determined by time-of-flight techniques. In each experiment the samples, including the ^{252}Cf standard, were contained in a fission chamber surrounded by a large volume (0.91 m³) of liquid scintillator loaded with gadolinium. The fission chamber detected the fission events, and the scintillator detected the accompanying prompt neutrons. The resulting data were analyzed to yield: $\bar{R}_p(E) = \bar{\nu}_p(E)(\text{fissile})/\bar{\nu}_p(^{252}\text{Cf})$. For ^{235}U and ^{239}Pu our results overlap, within the experimental uncertainty, the results of the evaluation of Manero and Konshin (1972), and in the case of ^{233}U our data show the same general structure apparent in the evaluation up to 0.5 MeV. Our $\bar{R}_p(E)$ for ^{233}U does not show the structure near 0.2 MeV obtained by Manero and Konshin.

Research sponsored by U.S. DOE Office of Reactor Research and Technology.

*Instrumentation and Controls Division.

2.20

FISSION-PRODUCT YIELD DATA
FROM THE US/UK JOINT EXPERIMENT
IN THE DOUNREAY PROTOTYPE
FAST REACTOR

J. K. Dickens S. Raman*

(Abstract of ORNL-6266, April 1986)

The United States and the United Kingdom have been engaged in a joint research program in which samples of fissile and fertile actinides have been incorporated in fuel pins and irradiated in the Dounreay Prototype Fast Reactor in Scotland. The purpose of this portion of the program is to study both the materials behavior and the nuclear physics results — primarily measurements of the fission-product yields in the irradiated samples and secondarily information on the amounts of heavy elements in the samples. In the measurements high-resolution detectors were used to observe (and quantitatively measure) the gamma rays and x-rays corresponding to the decay of several long-lived radioisotopes. Two series of measurements were made, one nine months following the end of the irradiation period and another approximately six months later. The samples were milligram quantities of actinide oxides of ^{248}Cm , ^{246}Cm , ^{244}Cm , ^{243}Cm , ^{243}Am , ^{241}Am , ^{244}Pu , ^{241}Pu , ^{240}Pu , ^{239}Pu , ^{238}Pu , ^{238}U , ^{236}U , ^{235}U , ^{234}U , ^{233}U , ^{231}Pa , ^{232}Th , and ^{230}Th that had been encapsulated in vanadium holders and exposed in the core to a total fluence of approximately 2.7×10^{22} "fast" neutrons over a period of about 12 months. The fission products identified were ^{91}Y , ^{95}Zr , ^{95}Nb , ^{103}Ru , ^{106}Rh (following decay of ^{106}Ru) $^{110\text{m}}\text{Ag}$, ^{125}Sb , ^{134}Cs , ^{137}Cs , ^{141}Ce , ^{144}Ce , ^{144}Pr , and ^{155}Eu . Because of uncertainties associated with the experiment (e.g., initial sample compositions, effective fission cross sections, etc.), not all the fission-product yields could be obtained on an absolute basis. Therefore, the absolute yields of the fission product ^{137}Cs in the various samples were designated as monitor data for determining the yields of the other fission products. The resulting relative-yield fission-product data were manipulated for

comparison with presently existing evaluated data; the comparisons are generally favorable and the exceptions are discussed. In addition, determinations of the heavy element contents of the samples provided information on both the initial sample composition and the actinides created during the irradiation.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Technology Support Programs.

* Physics Division.

2.21

YIELDS OF FISSION PRODUCTS PRODUCED BY THERMAL-NEUTRON FISSION OF ^{243}Cm

J. K. Dickens J. W. McConnell*

[Abstract of *Phys. Rev. C* **34**(2), 722 (1986)]

On the basis of measured yields for 72 gamma rays and known nuclear data, cumulative fission-product yields were deduced for 69 fission products having half lives between 36 seconds and 65 days representing 41 mass chains created during thermal-neutron fission of ^{243}Cm .

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Physics Division.

2.22

FISSION PRODUCT YIELDS FOR FAST NEUTRON FISSION OF $^{243,244,246,248}\text{Cm}$

J. K. Dickens

[Abstract of *Nucl. Sci. Eng.* **96**, 8 (1987)]

Recent measurements of relative yields for ^{95}Zr , ^{125}Sb , ^{137}Cs , ^{141}Ce , ^{144}Ce , and ^{155}Eu for fast neutron fission of samples enriched in the actinides $^{243,244,246,248}\text{Cm}$ have been combined with a simple mass-distribution model to predict complete mass distributions for fast neutron fission of each of these four curium actinides. Complete descriptions of the data analysis and of the model and its application and limitations are given.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.23

STUDY OF RADIONUCLIDES CREATED BY $^{57}\text{Ni}(\gamma, xn \gamma p)$ REACTIONS FOR BREMSSTRAHLUNG PHOTONS PRODUCED BY 140-MeV ELECTRONS

J. K. Dickens

(Abstract of ORNL/TM-9764, March 1986)

Twelve radionuclides from ^{48}V to ^{57}Ni produced by photon interactions with a sample of elemental Ni have been studied to obtain relative yields of these reaction products. Precision half lives were determined for ^{56}Ni and ^{57}Ni . For ^{56}Ni , $T_{1/2} = 6.08 \pm 0.03$ days, in agreement with previous measurements. For ^{57}Ni , $T_{1/2} = 35.54 \pm 0.05$ hr, in agreement with the 1982 measurement of Grutter but ~ 0.5 hr shorter than earlier measurements. Relative yields of the 127-keV, 1758-keV, and 1919-keV gamma rays following decay of ^{57}Ni were determined with respect to the 1338-keV gamma ray of that decay and the results agree better with measurements of Grutter and of Gatrousis *et al.* than they do with the Lederer *et al.* evaluation.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.24

HALF LIFE OF ^{57}Ni

J. K. Dickens

[Abstract of *J. Radioanal. Nucl. Chem. Letters* **103**, 273 (1986)]

The half life of ^{57}Ni has been measured by Ge(Li) gamma-ray spectroscopy. The ^{57}Ni radioisotope was created by bremsstrahlung impinging on a sample of elemental Ni. Time change of the activity of the 1377.6-keV gamma ray following decay of ^{57}Ni was analyzed to obtain a half life of 35.54 ± 0.05 hr for ^{57}Ni .

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.25

**NEUTRON AND GAMMA-RAY FLUENCES
IN A TOKAMAK ENVIRONMENT
DUE TO A POINT SOURCE
SIMULATING D-T FUSION PLASMA
NEUTRON PRODUCTION**

J. K. Dickens

(Abstract of a talk presented at a Colloquium on Experiments at the Princeton TFTR and Theoretical Comparisons, Nuclear Engineering Department, Rensselaer Polytechnic Institute, Troy, NY, September 15, 1986)

Moderate resolution spectral distributions of high-energy neutrons ($0.9 \leq E_n \leq 14.5$ MeV) and of high-energy gamma rays ($0.4 \leq E_\gamma \leq 9.4$ MeV) due to a D + T neutron point source simulating the extended fusion plasma neutron source in the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory are reported. A D-T neutron generator was positioned inside of the vacuum vessel at ten different locations around the torus. Neutrons and gamma rays were detected by a liquid-scintillator-based detector with electronic pulse-shape discrimination to differentiate between events in the detector due to incident neutrons and those due to incident gamma rays. The detector was placed on the median plane of the reactor at 8.85 m from its geometric center. Two spectral distributions, one for neutrons and the other for gamma rays, were obtained for each measurement location.

The neutron data have been compared with three-dimensional Monte Carlo calculations. An extensive computer program to model the Princeton Tokamak was developed for these computations. Overall, the calculated and experimental data are in good agreement.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.26

**MEASUREMENTS OF THE NEUTRON
AND GAMMA-RAY FLUENCES IN THE
TFTR TEST CELL DUE TO A POINT
SOURCE SIMULATING D-T FUSION
PLASMA NEUTRON PRODUCTION**

**J. K. Dickens J. W. McConnell^{*}
K. M. Chase[†] H. W. Hendel[†]
E. B. Nieschmidt[†] F. Y. Tsang[†]**

[Abstract of *Fusion Tech.* 12, 270 (1987)]

Spectral distributions of high-energy neutrons ($0.9 \leq E_n \leq 14.5$ MeV) and of high-energy gamma rays ($0.4 \leq E_\gamma \leq 9.4$ MeV) due to a deuterium-tritium (D+T) neutron point source simulating the extended fusion plasma neutron source in the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory are reported. A D-T neutron generator was positioned inside of the vacuum vessel at ten different locations around the torus. Neutrons and gamma rays were detected by a liquid-scintillator-based detector (4.65-cm diam $\times$ 4.22 cm high) with electronic pulse-shape discrimination to differentiate between events in the detector due to incident neutrons and those due to incident gamma rays. The detector was placed on the median plane of the reactor at 8.85 m from the geometric center of the TFTR. Two spectral distributions, one for neutrons and the other for gamma rays, were obtained for each measurement. The neutron data exhibit a high-energy peak dominated by uncollided primary-energy neutrons and a low-energy contribution from the scattered neutrons. The gamma-ray data exhibit a high-energy contribution due to neutron capture gamma rays and a low-energy contribution due to gamma rays following neutron inelastic scattering reactions.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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Modelling and Evaluation of Cross Sections

2.27

VALIDATION OF THE TNG CODE WITH DOUBLE DIFFERENTIAL (n,xn) DATA AT 14 AND 26 MeV

C. Y. Fu

[Abstract of paper presented at the Fifth Coordination Meeting of Participants in the Office of Basic Energy Sciences Program to Meet High-Priority Nuclear Data Needs of the Office of Fusion Energy, Argonne, IL, September 17-19, 1986; Proc. DOE/ER/02490-4, p. E-5 (1986)]

A simplified method for approximating precompound nuclear reaction effects in the TNG Hauser-Feshbach code for the calculation of double differential cross sections is validated. The method is developed from existing quantum-mechanical formulas of unified compound and precompound reaction theories. The compound part of the unified formulas is made identical to the Hauser-Feshbach formula by applying the unified level density formulas derived previously for the two theories. The precompound part, much more complicated than the compound part, is simplified and globally parameterized for practical purposes. Double differential (n,xn) cross sections at 14 and 26 MeV for iron, niobium, and bismuth calculated with global parameters are shown to be in good agreement with the available experimental data. In use at ORNL and JAERI, the TNG code has been applied with ease and success to the evaluation of double differential (n,xn) cross sections from 1 to 20 MeV for the dominant isotopes of chromium, manganese, iron, and nickel.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.28

ENERGY DEPENDENCE OF THE LOCAL OPTICAL POTENTIAL FOR NEUTRON-NUCLEUS SCATTERING

J. P. Delaroche*

P. P. Guss†

G. M. Honore‡

C. R. Howell†

R. L. Walter‡

D. C. Larson

D. M. Hetrick‡

J. A. Harvey

[Abstract of Neutron-Nucleus Collisions Conference, Glouster, OH, September 5-8, 1984; Proc. AIP Conf. No. 124, p. 310 (1985)]

A systematic study of the energy dependence of the local neutron optical potential up to 80 MeV has been performed using coupled channels analyses of a large set of neutron scattering and reaction observables.

Research sponsored by U.S. Department of Energy.

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2.29

CALCULATED NEUTRON-INDUCED CROSS SECTIONS FOR ^{52}Cr FROM 1 TO 20 MeV AND COMPARISONS WITH EXPERIMENTS

D. M. Hetrick*

C. Y. Fu

D. C. Larson

(Abstract of ORNL/TM-10417, September 1987)

Nuclear model codes were used to compute cross sections for neutron-induced reactions on ^{52}Cr for incident energies from 1 to 20 MeV. The input parameters for the model codes were determined through analysis of experimental data in this energy region. Discussion of the models used, the input data, the resulting calculations, extensive comparisons to measured data, and comparisons to the Evaluated Nuclear Data File (ENDF/B-V) for Cr (MAT 1324) are included in this report.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.30

CALCULATED NEUTRON-INDUCED CROSS SECTIONS FOR ^{53}Cr FROM 1 TO 20 MeV

K. Shibata* D. M. Hetrick†

(Abstract of ORNL/TM-10381, May 1987)

Neutron-induced cross sections of ^{53}Cr have been calculated in the energy regions from 1 to 20 MeV. The quantities obtained are the cross sections for the reactions $(n,n'\gamma)$, $(n,2n)$, $(n,n\alpha)$, $(n,p\gamma)$, (n,pn) , $(n,\alpha\gamma)$, (n,d) , (n,t) , $(n,^3\text{He})$, and (n,γ) , as well as the spectra of emitted neutrons, protons, alpha particles, and gamma rays. The precompound process was included above 5 MeV in addition to the compound process. For the inelastic scattering, the contribution of the direct interaction was calculated with DWBA.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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†Computing and Telecommunications Division.

2.31

CALCULATION AND EVALUATION OF $^{58,60}\text{Ni}$ FOR ENDF/B-VI

D. M. Hetrick*

[Abstract of paper presented at the Fifth Coordination Meeting of Participants in the Office of Basic Energy Sciences Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy, Argonne, IL, September 17-19, 1986; Proc. DOE/ER/02490-4 (1986)]

It has been shown that deficiencies exist in the neutron emission spectra from contributing reactions for nickel in the present Evaluated Nuclear Data File (ENDF/B-V). Gamma rays produced in the (n,p) and $(n,2n)$ reactions are significant for $E_\gamma < 0.5$ MeV, a gamma-ray energy region not represented in ENDF/B-V since measured data solely influenced the evaluation. Also, an isotropic angular distribution is given for the continuum (MT=91) which is not adequate for the wide incident neutron energy range between the threshold of the highest-energy discrete level and 20 MeV. Calculations for neutron-induced cross sections of $^{58,60}\text{Ni}$ from the

Hauser-Feshbach/precompound model code TNC are compared to both measured data and ENDF/B-V. An example of representing the energy-angle correlations of inelastically scattered neutrons in the new ENDF/B-VI format will be shown.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Computing and Telecommunications Division.

2.32

CALCULATED NEUTRON-INDUCED CROSS SECTIONS FOR $^{58,60}\text{Ni}$ FROM 1 TO 20 MeV AND COMPARISONS WITH EXPERIMENTS

D. M. Hetrick* C. Y. Fu
D. C. Larson

[Abstract of ORNL/TM-10219 (ENDF-344), June 1987]

Nuclear model codes were used to compute cross sections for neutron-induced reactions on both ^{58}Ni and ^{60}Ni for incident energies from 1 to 20 MeV. The input parameters for the model codes were determined through analysis of experimental data in this energy region. Discussion of the models used, the input data, the resulting calculations, extensive comparisons to measured data, and comparisons to the Evaluated Nuclear Data File (ENDF/B-V) for Ni (MAT 1328) are included in this report.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Computing and Telecommunications Division.

2.33

R-MATRIX ANALYSIS OF THE ^{239}Pu CROSS SECTIONS UP TO 600 eV

H. Derrien* G. de Sansure
R. B. Perez N. M. Larson†
Roger L. Macklin‡

[Abstract of *Trans. Am. Nucl. Soc.* 52, 635 (1986)]

The ENDF/B-V representation of the ^{239}Pu neutron cross sections in the resonance region is unsatisfactory. The single-level formalism is

used, necessitating a structured file 3 contribution. Furthermore, Salvatores *et al.* have stressed the need to extend the resolved resonance region above the present ENDF/B limit of 300 eV for the calculation of Doppler effect and self-shielded group cross sections. The purpose of our work is to improve the representation of the ^{239}Pu cross sections by using a multilevel formalism (which avoids the need for the file 3 contributions) and by extending the resolved resonance range from 300 up to 600 eV. The present resonance analysis is based on the Reich-Moore multilevel formalism and was performed with the Bayesian code SAMMY. More than 200 levels and 1000 resonance parameters are included in the analysis.

The fission cross sections computed from the parameters of our analysis are consistent with the liquid nitrogen-cooled sample measurements of Blons and with the high accuracy recent data from Weston and Todd. The three sample thickness transmission data of Harvey *et al.* are also accurately described.

The present resonance analysis improves on the ENDF/B-V description of the ^{239}Pu cross sections by using a multilevel formalism, which avoids the use of the awkwardly structured file 3, and by extending the resolved resonance description to 600 eV. Furthermore, the parameters obtained in this work describe accurately and consistently the experimental data, hence providing a firm basis for reactor design calculations.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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2.34

R-MATRIX ANALYSIS OF THE ^{239}Pu CROSS SECTIONS UP TO 1 keV

H. Derrien^{*} G. de Sanssoure
R. B. Perez N. M. Larson[†]
Roger L. Macklin[‡]

(Abstract of ORNL/TM-10098, June 1986)

We report here the results of an R-matrix resonance analysis of the ^{239}Pu neutron cross sec-

tions up to 1 keV. After a description of the method of analysis we list the nearly 1600 resonance parameters obtained and present extensive graphical and numerical comparisons between calculated and measured cross-section and transmission data.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^{*}Centre D'Etudes Nucleaires de Cadarache, France.

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2.35

EVALUATION OF THE NEUTRON CROSS SECTIONS FOR PU-240

L. W. Weston E. D. Arthur^{*}

[Abstract of ORNL/TM-10386 (ENDF-343), April 1987]

The present evaluation is proposed to supersede the ENDF/B-V, Revision 2 file for ^{240}Pu by L. W. Weston *et al.*, dated September, 1978. In this work, resonance parameters, cross sections, energy distributions, and angular distributions have been modified. These changes are outlined in detail and appropriate references included.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

^{*}Los Alamos National Laboratory, Los Alamos, NM.

2.36

R-MATRIX ANALYSIS OF THE ^{241}Pu CROSS SECTIONS UP TO 100 eV

H. Derrien^{*} N. M. Larson[†]
G. de Sanssoure R. B. Perez

[Abstract of Nucl. Sci. Eng. 96, 58 (1987)]

The ^{241}Pu total cross-section measurement of Kolar and Carraro and the neutron fission cross-section measurements of Blons *et al.* and Weston and Todd were analyzed with the R-matrix resonance analysis program SAMMY, which uses Bayes' equation to extract resonance parameters from the experimental data. A set of Reich-Moore-type resonance parameters that describes the cross sections up to 100 eV was obtained. It

is shown that existing data are not adequate for a precise evaluation of the resonance cross sections, and the need for additional work is discussed.

Research sponsored by U.S. DOE Office of Reactor Research and Technology.

*Centre d'Etudes Nucleaires de Cadarache, France.

†Computing and Telecommunications Division.

Reviews

2.37

CURRENT STATUS OF DECAY HEAT MEASUREMENTS, EVALUATIONS, AND NEEDS

J. K. Dickens

[Abstract of ORNL/TM-10094, July 1986; also paper presented at the American Nuclear Society National Topical Conference on Reactor Physics and Safety, Saratoga Springs, NY, September 17-19, 1986; Proc. NUREC/CP-0080, Vol. 2, p. 671 (1986)]

Over a decade ago serious concern over possible consequences of a loss-of-coolant accident in a commercial light water reactor prompted support of several experiments designed specifically to measure the latent energy of beta-ray and gamma-ray emanations from fission products for thermal reactors. This latent energy was termed Decay Heat. At about the same time the American Nuclear Society convened a working group to develop a standard for use in computing decay heat in real reactor environs primarily for regulatory requirements. This working group combined the new experimental results and best evaluated data into a standard which was approved by the ANS and by the ANSI. The primary work since then has been (a) on improvements to computational efforts and (b) experimental measurements for fast reactors. In addition, the need for decay-heat data has been extended well beyond the time regime of a loss-of-coolant accident; new concerns involve, for example, away-from-reactor shipments and storage. The efficacy of the ANS standard for these longer time regimes has been a subject of study with generally positive results. However, a specific problem, namely, the consequences of fission-product neutron capture, remains contentious. Satisfactory resolution of this problem merits a high priority.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.38

REVIEW OF NEW INTEGRAL DETERMINATIONS OF DECAY HEAT

J. K. Dickens

(Abstract of paper presented at the Specialists' Meeting on Data for Decay Heat Predictions, Studsvik, Sweden, September 7-10, 1987)

Over a decade ago, concern over possible serious consequences of a loss-of-coolant accident in a commercial light-water reactor prompted support in several countries of several experiments designed specifically to measure the decay heat of beta-ray and gamma-ray emanations from fission products for thermal reactors. In 1979, a new standard for use in computing decay heat in real reactor environs (for example, for regulatory requirements) was approved by the American Nuclear Society. Since then there have been additional experimental measurements, in particular for fission induced by fast neutrons. In addition, the need for decay-heat data has been extended well beyond the time regime of a loss-of-coolant accident. The efficacy of the 1979 ANS standard has been a subject of study with generally positive results. However, a specific problem, namely, the consequences for decay heat of fission-product neutron capture merits further experimental study.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.39

EVALUATING NUCLEAR DATA UNCERTAINTY: PROGRESS, PITFALLS, AND PROSPECTS

R. W. Peele

(Abstract of paper presented at the IAEA Specialists' Meeting on Covariance Methods and Practices in the Field of Nuclear Data, Rome, Italy, November 17-19, 1985)

The reasons for including variance-covariance information in evaluated nuclear data files are reviewed. Accomplishments and obstacles in meeting these needs are identified. The capability to develop and utilize evaluated cross-section covariance files has been largely demonstrated, but comprehensive files of soundly based covariance data remain to be evaluated and not all types of cross-section data have yet been included. The status of the ENDF-VI covariance formats is discussed. Priorities are suggested for further development. Most effort should be concentrated to fully develop the capability to estimate the nuclear data uncertainties in quantities calculated for a broad energy spectrum.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.40

NUCLEAR DATA COVARIANCE METHODS AND PRACTICES, THE REPORT OF A WORKING GROUP

R. W. Peele

(Abstract of a Working Group Report to be published by the IAEA with the proceedings of the IAEA Specialists' Meeting on Covariance Methods and Practices in the Field of Nuclear Data, Rome, Italy, November 17-19, 1986)

The needs for evaluated nuclear data covariance information were reviewed for various applications: fission reactor core physics, shielding, fuel cycle, pressure vessel surveillance, and delayed neutron parameters; and fusion reactor blanket, shielding, and dosimetry. Covariance data needs differed greatly among the applications. The need for covariance data for secondary energy and angle distributions arises only

for fusion blankets and possibly for shield design, and only for pressure vessel surveillance and fast reactor shielding is need found for a fine energy grid in the processed covariance data. With identified exceptions, the techniques exist to evaluate, represent, process, and utilize nuclear data covariance information. One basic data evaluation problem is that papers describing cross section experiments often do not provide sufficient information to allow construction of the covariance matrix of the results given. Some possible international efforts are listed for improving covariance data and usage.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.41

UNDERSTANDING NUCLEAR FISSION AND RADIOACTIVITY

J. K. Dickens

(Abstract of oral presentation given at the Teachers/Media Seminar on Understanding Radioactivity and Radioactive Waste, Knoxville, TN, April 23, 1986)

A prerequisite to understanding radioactive waste and radioactive waste management is an understanding of nuclear fission, how power is developed from this energy source, and what makes up the residue from the use of nuclear fission as the energy source. We present a cogent discussion on a conceptual level (with a historical perspective) of the physics fundamentals pertaining to nuclear fission and radioactivity. The discussion will also include basic engineering concepts leading to an understanding of the application of nuclear fission to produce electric power.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.42

THE FUTURE/DEMISE OF COMMERCIAL NUCLEAR POWER IN THE U.S.

J. K. Dickens

(Abstract of a public forum talk presented at Arizona State University, Phoenix, AZ, September 26, 1985; also presented at Concord College, Athens, WV, April 8, 1987 under the title "Reactor Safety and the Status of Commercial Nuclear Energy in the U.S.")

Of all of the major industrial activities in the United States that of commercial electricity production by nuclear power is probably the most widely discussed in public forums today. Scarcely a day passes without a report on some aspect of nuclear power in our news media. A review of the (brief) history of commercial nuclear power especially in the context of other social changes in this country provides a reasonable explanation for present-day interest in this topic. Indeed, several paradoxes concerning nuclear power provide clues to its current status as a viable contributor to our society. As an example of a paradox, nuclear power has been a substantial growth industry for fifteen years, and yet companies involved in this industry have been considered as poor investments for nearly all classes of investors. As a second example of a paradox, nuclear power is perceived by many as the most dangerous commercial undertaking ever conceived, and yet the actual experience in terms of accidental human deaths or injuries indicates that nuclear power is at present the safest industry in the United States. As a third example of a paradox, there is a strong demand for professional and skilled workers to fill many job openings in nuclear power production, and yet it is well known that there have been no new nuclear power plants initiated in this country for over seven years. Indeed, this last fact provides a fourth example of a paradox in that this cessation of growth at the production level has occurred despite federal governmental recognition of the need to increase this nation's self-sufficiency in energy production and the concomitant recognition and support of the role of nuclear power in trying to fulfill this goal.

Why, then, has the present situation come to pass? A review of the middle-class rebellion (suggested some years ago by Llewellyn King) provides one answer; indeed, following the logical sociological implications of this concept provides additional clues not only to how we have gotten where we are but also to where we are likely to be headed in the future. Are we headed in the direction we wish to be headed in? That question devolves into a determination of leadership (but not authority!) in our country. Based on reasonable analyses of our recent history, in which the evolution of nuclear power may be the most discussed aspect but is certainly only a modest portion of the total, the question posed is rhetorical, for the answer is always "yes." Is this result an example of a fifth paradox? But perhaps more important — can we define the direction we are headed in? Insofar as nuclear power is concerned the answer is that we can. The U.S. will increase its dependence on commercial nuclear power for electric power production from the present amount of 13 to 14% to a maximum of perhaps 20% within the next decade, and then will slowly but certainly phase out light water reactor nuclear electric power production. What the effects of this course of action will be on the fabric of our society should be of concern to all of us.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.43

REPORTS ON NUCLEAR DATA ACTIVITIES FOR THE DOE NUCLEAR DATA COMMITTEE

D. C. Larson

[Abstract of BNL-NCS-37699, p. 135 (May 1986) and of BNL-NCS-39266, p. 141 (May 1987)]

These reports were prepared for the DOE Nuclear Data Committee and cover work performed at ORNL since January 1985 in areas of nuclear data of relevance to the U.S. applied nuclear energy program. These reports were mostly generated through a review of abstracts of work completed to the point of being subjected to some form of publication in the open literature,

formal ORNL reports, ORNL technical memoranda, progress reports, or presentations at technical conferences. As much as possible we have reproduced the complete abstracts of the original publications with only minor editing. In a few cases progress reports were written specifically for this publication. The editor has selected the materials to be included in these reports on the basis of perceived interests of DOE Nuclear Data Committee members and cannot claim completeness.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

2.44

MEASUREMENT ACTIVITIES

D. C. Larson

(Abstract of Task Force A report of the Fifth Coordination Meeting of Participants in the Office of Basic Energy Sciences Program to Meet High Priority Nuclear Data Needs of the Office of Fusion Energy, Argonne, IL, September 17-19, 1986)

By mutual agreement of its members at the beginning of the task force meeting, most of the

time was spent in review of the data requests provided prior to the meeting. In the review process, we attempted to determine if the data base for the reaction under consideration was adequate, whether further measurements were needed, and if evaluation of existing data needed updating. The data needs were divided into six areas: (1) fuel cycle reactions, (2) neutron multiplying and tritium breeding data, (3) neutron and gamma-ray emission data, (4) dosimetry cross sections, (5) activation cross sections, and (6) radiation damage — charged particle production cross sections. We were able to review the first four areas in fair detail; the fifth area was superficially reviewed, and the sixth was briefly reviewed. Our findings for these data needs are presented.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

Section 3

SYSTEMS ANALYSIS AND SHIELDING

3.0. INTRODUCTION

D. G. Cacuci

The Systems Analysis and Shielding Section comprises four groups whose major research activities are in the areas of: (a) radiation and particle transport and shielding for civilian and military applications; (b) design and analysis of advanced nuclear reactors; (c) development of analytical and computational methods and models both for general purpose and specific applications; and (d) reliability and human factors.

The radiation transport and shielding activities devoted to advanced nuclear reactors for civilian applications have been focused on two major efforts: (1) the joint US/Japan program of shielding experiments performed at the Tower Shielding Facility, and (2) the further development and application of the TORT three-dimensional discrete ordinates code. The first effort represents a multi-year collaboration between the U.S. and Japan to address the leading in-vessel shielding concerns relating to the development of advanced liquid metal reactor (LMR) concepts. Complementary efforts to analyze the shielding requirements for advanced LMR and High Temperature Gas-Cooled Reactors (HTGR) concepts were also performed. (Note that the Department of Energy has categorized work for the LMR and recently for the HTGR programs as "Applied Technology" so explicit references to this work cannot be included in this report.)

The capabilities of the TORT code have been further expanded and the code is now being used to solve important and very difficult problems, such as the vessel embrittlement problem in ORNL's High Flux Isotope Reactor. The application that originally motivated TORT's development, i.e., the computation of neutron and gamma-ray transport into large concrete buildings at Hiroshima and Nagasaki, was brought to a significant interim conclusion and contributed substantially to the U.S. position in an international debate regarding LD₅₀.

Research has also continued on pre-analysis and post-analysis of integral experiments on fusion neutronics conducted at the Japan Atomic Energy Research Institute (JAERI), as part of a JAERI/DOE collaboration. Also, the scope of the High-Energy Transport Code (HETC) has been significantly extended to include energy ranges up to 20 TeV; this extension is essential for future shielding and detector design calculations for the proposed Superconducting Super Collider.

Within the framework of the ORNL Fast Track Program in support of the Strategic Defense Initiative (SDI), considerable progress has been achieved in the development of improved hydrocode methods and algorithms for calculating the penetration of hypervelocity projectiles in solid and layered shield assemblies. These developments include the addition of combinatorial geometry, fine-to-coarse mesh truncation procedures for accelerating execution times, algorithms to account for the internal energy and momentum in the computational cells, and implementation of improved methods for calculating stress failure modes. Comprehensive analyses have also been carried out to determine the effectiveness of multilayered, multimaterial SDI kinetic energy and laser weapon shields in protecting a silicon-based electronic system against various modes of natural and man-made nuclear radiation. These modes include Van Allen belt, solar, galactic cosmic radiation of space and space detonated nuclear weapons, and directed energy weapons. Also, studies have been performed to identify the impact of nuclear weapon blast, thermal, and radiation effects on materials proposed for use in advanced military aircraft.

Calculations to aid in the design of the Advanced Neutron Source (ANS) have been conducted in the areas of neutronics and thermal hydraulics analyses of the reactor core and neutronics analyses of the cold source. A significant effort was directed at developing a cross-section library specifically for use in ANS analyses. Core design calculations led to the decision that D₂O, rather than H₂O, would be the primary coolant in the ANS. Additional calculations yielded an optimized fuel distribution for an ANS single core design. Optimization of the size and shape of the ANS cold source is now underway.

Safety evaluations were prepared for the U.S. Nuclear Regulatory Commission (NRC) on the conceptual design of the Standard Modular HTGR. Technical evaluations and reports were also prepared in support of NRC's safety evaluation of the continuing Technical Specification Upgrade Program for the Fort St. Vrain reactor.

Research on the fundamental properties of the Boltzmann transport equation has continued; noteworthy is the co-authorship of a definitive book on boundary value problems in abstract kinetic theory. A new mathematical formalism for solving general nonlinear equations has been developed. Work on developing mathematical methods for modeling troop engagements on battlefields has led to the introduction of nonlinear partial differential equations to describe the space and time behavior of two homogeneous forces in conflict.

The central effort in the systems reliability area is the continued development and operation of the Centralized Reliability Data Organization (CREDO), jointly sponsored by DOE and Japan's PNC. The primary purpose of CREDO is to provide data and data analysis services to DOE and PNC contractors in support of activities such as the design of DOE's inherently safe modular breeder concepts, and PNC's probabilistic risk assessment of its MONJU LMR.

Human reliability efforts have been primarily oriented towards the development and evaluation of computer simulation models to provide dynamic integration between a plant process model, a network simulation model of cognitive tasks, and a knowledge-based model of diagnostic expertise. Other human factors research activities include: human factors reviews of the Savannah River and the (four) ORNL reactors, and development of human factors guidelines for the design of Rockwell's Sodium Advanced Fast Reactor.

Radiation Transport and Shielding for Fission Reactors

3.1

DEVELOPMENT OF SIMPLIFIED METHODS AND DATA BASES FOR RADIATION SHIELDING CALCULATIONS FOR CONCRETE

S. I. Bhuiyan* R. W. Roussin
J. L. Lucius† J. H. Marable
D. E. Bartine‡

(Abstract of ORNL/TM-3629, June 1986)

Two simplified methods have been developed which allow rapid and accurate calculations of the attenuation of neutrons and gamma rays through concrete shields. One method, called the BEST method, uses sensitivity coefficients to predict changes in the transmitted dose from a fission source that are due to changes in the composition of the shield. The other method uses transmission factors based on adjoint calculations to predict the transmitted dose from an arbitrary source incident on a given shield. The BEST method, utilizing an exponential model that is shown to be a significant improvement over the traditional linear model, has been successfully applied to slab shields of standard concrete and rebar concrete. It has also been tested for a special concrete that has been used in many shielding experiments at the ORNL Tower Shielding Facility, as well as for a deep-penetration sodium problem. A comprehensive data base of concrete sensitivity coefficients generated as part of this study is available for use in the BEST model. For problems in which the changes are energy independent, application of the model and data base can be accomplished with a desk calculator. Larger-scale calculations required for problems that are energy dependent are facilitated by employing a simple computer code, which is included, together with the data base and other calculational aids, in a data package that can be obtained from the ORNL Radiation Shielding Information Center (request DLC-102/CONSENT). The transmission factors used by the second method are a byproduct of the sensitivity calculations and are mathematically

equivalent to the surface adjoint function ϕ^* , which gives the dose equivalent transmitted through a slab of thickness T due to one particle incident on the surface in the g th energy group and j th direction. A second data package available from RSIC (request DLC-101/ADVISE) contains the dose transmission factors and a computer code that can fold the transmission factors to represent sources with arbitrary neutron or gamma-ray energy and angle distributions.

Research sponsored by Defense Nuclear Agency.

*Bangladesh Atomic Energy Commission.

†Computing and Telecommunications Division.

‡Engineering Technology Division.

3.2

EVALUATION AND TESTING OF DOUBLE DIFFERENTIAL $F_0(n, n')$ CROSS SECTIONS

C. Y. Fu D. M. Hetrick*

[Abstract of *Trans. Am. Nucl. Soc.* 53, 409 (1986)]

Analyses of integral experiments that include thick (>15 -cm) iron regions have shown a consistent underprediction of neutron transmission. One explanation that has been offered is that the angular distributions of the inelastically scattered neutrons in the continuum in the current ENDF/B-V iron evaluation were assumed to be isotropic. In reality, these distributions are forward peaked, especially if the incident neutron energies are a few MeV greater than the continuum Q -value. The forward peaking also increases with increasing outgoing neutron energies, giving rise to correlated energy-angle distributions. To understand their effects on neutron penetration through iron, we generated such correlated distributions in a special update of the ENDF/B-V Mod-3 iron evaluation and reanalyzed an iron sphere problem with a central DT source. It is shown that the predicted neutron leakage using the revised data set is increased, particularly near 10 MeV where the increase is 80%. A reduction of the total inelastic cross section above 3 MeV, a result of better nuclear model fit to the available

data, also enhances neutron leakage, especially near 5 MeV where the reduction is the largest.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

3.3

UPDATE OF ENDF/B-V MOD-3 IRON: NEUTRON-PRODUCING REACTION CROSS SECTIONS AND ENERGY-ANGLE CORRELATIONS

C. Y. Fu D. M. Hetrick*

[Abstract of ORNL/TM-9964 (ENDF-341), July 1986]

An update of the ENDF/B-V Mod-3 evaluation for natural iron is described. The cross sections of (n,n') and $(n,2n)$ reactions are revised. Energy-angle correlations in the secondary (n,n') neutrons are introduced in the ENDF/B-V formats. Anisotropic angular distributions are provided for the secondary neutrons in $(n,2n)$, (n,np) , and $(n,n\alpha)$ reactions. Relevant integral results, microscopic data, and nuclear model calculations that influence the revised results are summarized.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

3.4

VELM61 AND VELM22: MULTIGROUP CROSS-SECTION LIBRARIES FOR SODIUM-COOLED REACTOR SHIELD ANALYSIS

C. Y. Fu D. T. Ingersoll

(Abstract of ORNL/TM-10302, April 1987)

Two coupled neutron and photon multigroup cross-section libraries, derived from ENDF/B-V nuclear data, are described. The energy group structures, $61n/23\gamma$ and $22n/10\gamma$, are subsets of the Vitamin-E $174n/38\gamma$ group structure and are tailored to the iron and sodium resonances, windows, and capture gamma-ray spectra. Each of the two libraries are available in two formats, the AMPX master format and the ANISN format.

Cross sections for all materials in the Vitamin-E library were collapsed using a standard energy weighting function, and in addition, several cross-section sets for each of the major constituents of commercial grade sodium, stainless steel (types 304 and 316), and carbon steel were derived using several problem-dependent weighting functions for averaging the fine groups. Effects of various group structures and weighting functions on the accuracy of the broad group libraries are studied by ANISN analysis of a typical sodium-iron shield configuration.

Research sponsored by U.S. DOE Office of Liquid Metal Converter Reactor.

3.5

GROUP STRUCTURE AND WEIGHTING FUNCTION EFFECTS ON NEUTRON PENETRATION THROUGH THICK SODIUM-IRON SHIELDS

C. Y. Fu D. T. Ingersoll

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 1, p. 158 (1987)]

The effects of group structures and weighting functions on neutron penetration through a thick Na-Fe geometry are studied. The recommended broad-group ($61n/23\gamma$ -neutron/ 23γ -gamma-ray) and few-group ($22n/10\gamma$ -neutron/ 10γ -gamma-ray) structures are tailored to the sodium and iron resonances, windows, and capture gamma-ray spectra. The best weighting functions are shown to be fine-group fluxes selected from a few kev locations in the geometry. These group structures and weighting functions, relative to existing group structures and conventional weighting functions, improve the accuracy of the computed $61n/23\gamma$ -neutron-group Bonner ball responses by up to one hundred percent and of the computed $22n/10\gamma$ -neutron-group results by up to six hundred percent.

Research sponsored by U.S. DOE Liquid Metal Converter Reactor Program.

3.6

RADIATION SHIELDING RESEARCH AT ORNL: PAST — PRESENT — FUTURE

D. T. Ingersoll

(Abstract of oral presentation given at a Technical Seminar, Georgia Institute of Technology, Atlanta, GA, October 17, 1985)

The different elements of shielding research performed at the Oak Ridge National Laboratory are discussed. Specific examples of the analytical and experimental programs for the Fast Flux Test Facility and the High Temperature Gas-Cooled Reactor programs demonstrate past efforts. A description of the Hiroshima/Nagasaki concrete buildings project demonstrates current activities and highlights the typical relationship between shielding applications, methods development, and experimental testing. A few projections for the near-term and long-term direction of shielding research are also given.

Research sponsored by U.S. DOE Office of Breeder Reactor Systems.

3.7

JASPER: A JOINT U.S.-JAPAN PROGRAM OF EXPERIMENTAL SHIELDING RESEARCH

D. T. Ingersoll N. Ohtani*

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 2, p. 346 (1987)]

A cooperative shielding research program between the U.S. Department of Energy and Japan's Power Reactor and Nuclear Fuel Development Corporation has been initiated. The program includes six specific shielding integral experiments to be performed at the Oak Ridge National Laboratory Tower Shielding Facility and analyzed by both U.S. and Japanese participants. Planned experiments include studies of (1) attenuation in radial shield mockups, (2) neutron

streaming in a fission gas plenum, (3) shield effectiveness of different axial shield designs, (4) neutron streaming in narrow gaps, (5) source multiplication effects within in-vessel stored fuel assemblies, and (6) sodium activation in an intermediate heat exchanger mockup. The first experiment, which included numerous configurations containing steel, graphite, and boron carbide, has been completed and initial results are presented. The remaining four experiments, which are in various stages of planning, fabrication and execution, are described briefly.

Research sponsored by U.S. DOE Liquid Metal Converter Reactor Program.

* Power Reactor and Nuclear Fuel Development Corporation, Japan.

3.8

THE ROLE OF INTEGRAL EXPERIMENTS AND NUCLEAR CROSS SECTION EVALUATIONS IN SPACE NUCLEAR REACTOR DESIGN

D. L. Moses R. D. McKnight*

[Abstract of paper presented at the Fourth Symposium on Space Nuclear Power Systems, Albuquerque, NM, January 12-16, 1987; Trans. CONF-870102-Summa., p. 161 (1987)]

Current interest in developing space nuclear power systems includes conceptual designs for SP-100 and the Multimegawatt Reactor Program. The proposed designs utilize materials (i.e., nuclear data) and geometries (i.e., analytical methods) which are not tested by current operating fast or thermal systems. The need for integral experiments in fast critical assemblies in support of these space nuclear power systems is clearly evident. Recent critical experiments in ZPPR have addressed some of the design issues. However, there are additional valuable, though somewhat dusty, integral data available which could provide useful insights to some of the nuclear data questions which are unique to the space nuclear power systems.

Research sponsored by U.S. DOE Office of Space Nuclear Power.

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3.9

EXPERIMENTAL VERIFICATION OF CALCULATED NEUTRON STREAMING IN THE BOTTOM REFLECTOR AND CORE SUPPORT REGIONS OF A LARGE SCALE HTGR DESIGN CONCEPT

C. O. Slater F. J. Muckenthaler
D. T. Ingersoll

[Abstract of *Nucl. Sci. Eng.* 97(2), 123 (1987)]

This paper describes the analysis of an ORNL Tower Shielding Facility experiment in which measurements were made of neutrons streaming through a mockup of a section of the lower core support structure of a large scale High-Temperature Gas-Cooled Reactor (HTGR) design concept. The analysis was performed with the same calculational methods used for an analy-

sis of the HTGR design itself, the purpose of the experiment being to provide data against which the validity of the calculational methods could be tested. This paper also summarizes the HTGR design calculation results and describes how they affected the design and objectives of the TSF experiment. Comparisons of the neutron detector responses observed in the experiment with calculated responses showed satisfactory agreement in most cases, and the implications of these results for the HTGR shield design are highlighted. Among other conclusions, it was determined that (1) the calculational methods are adequate, (2) neutron streaming through the HTGR core support structure is predicted reasonably well, and (3) the thermal-neutron fluence levels at the HTGR lower plenum sidewall are probably overestimated by at most a factor of 2.3.

Research sponsored by U.S. DOE Office of Advanced Reactor Programs.

Radiation Transport and Shielding for Fusion Reactors

3.10

THE ORNL FUSION INTEGRAL EXPERIMENT/ANALYSIS PROGRAM

R. T. Santoro J. M. Barnes*
R. G. Alsmiller, Jr. J. D. Drischler

[Abstract of *Trans. Am. Nucl. Soc.* 52, 113 (1986)]

During the past seven years, the Oak Ridge National Laboratory has been tasked by the Office of Fusion Energy, U.S. Department of Energy, to conduct a series of integral experiments to provide data for validating the radiation transport methods and nuclear data that are used for nuclear design calculations for fusion reactors. This paper reviews the research that was carried out and summarizes the results that were obtained for some of the experiments.

The program focused on two kinds of experiments: (a) the measurement of neutron and gamma-ray spectra resulting when 14-MeV neu-

trons were incident on bulk shields of different compositions and thickness and (b) the measurement of neutron and gamma-ray spectra as a function of detector location relative to the mouths of straight cylindrical ducts of different length-to-diameter ratios when 14-MeV neutrons were incident on the ducts.

These studies revealed that ENDF/B-IV and -V cross-section data are generally adequate for the analysis of both shielding and streaming data, although higher order Legendre data are necessary for analysis of neutron streaming through ducts. Monte Carlo methods that use continuous cross-section data (e.g., MCNP) were found to be appropriate for streaming analysis, but they must be used cautiously when streaming and deep penetration occur in the same geometry. The discrete ordinates method was found to be adequate for shielding studies but severely limited in streaming cases.

Research sponsored by U.S. DOE Office of Fusion Energy.

*Computing and Telecommunications Division.

3.11

**MONTE CARLO AND DISCRETE
ORDINATES CALCULATIONS FOR
14-MeV NEUTRONS STREAMING
THROUGH A STAINLESS STEEL
DUCT: COMPARISONS WITH
EXPERIMENT II**

R. T. Santoro J. M. Barnes*
R. G. Alsmiller, Jr. J. D. Drischler

[Abstract of ORNL/TM-9885, December 1985; also *Nucl. Instru. Methods in Phys. Res. A250*, 557 (1986)]

Measured and calculated neutron energy spectra from 14-MeV neutrons streaming through stainless steel ducts having length-to-diameter ratios of 14.8 and 38.2 are compared in this paper. The measured data were obtained using an NE-213 liquid scintillator and the calculated data were obtained using the Monte Carlo code MCNP and the discrete ordinates code DOT 4.3. For both duct geometries, the spectra calculated using the MCNP code are in reasonable agreement with the measured data ranging from a few percent to a factor of two, depending on the detector location and duct. The spectra calculated using the DOT code are in fair agreement (30%) for cases where the detector is on the duct axis, but are in poor agreement, up to an order of magnitude, when the detector is off axis.

Research sponsored by U.S. DOE Office of Fusion Energy.

*Computing and Telecommunications Division.

3.12

**COMPARISONS OF CALCULATED AND
MEASURED SPECTRAL DISTRIBUTIONS
OF NEUTRONS FROM A 14-MeV
NEUTRON SOURCE INSIDE THE
TOKAMAK FUSION TEST REACTOR**

R. T. Santoro J. M. Barnes*
R. G. Alsmiller, Jr. M. B. Emmett*
J. D. Drischler

[Abstract of ORNL/TM-9888, December 1985; also *Fusion Tech.* 11, 420 (1987); also *Trans. Am. Nucl. Soc.* 52, 114 (1986)]

A recent paper presented neutron spectral distributions (energy ≥ 0.91 MeV) measured at various locations around the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory. The neutron source for the series of measurements was a small deuterium-tritium generator placed at various positions in the TFTR vacuum chamber. The results of neutron transport calculations are presented and compared with these experimental data. The calculations were carried out using Monte Carlo methods and a very detailed model of the TFTR and the TFTR test cell. The calculated and experimental fluences per unit energy are compared in absolute units. Significant areas of agreement and disagreement are found for different combinations of source and detector positions.

Research sponsored by U.S. DOE Office of Fusion Energy.

*Computing and Telecommunications Division.

High-Energy Radiation and Particle Transport

3.13

LOW-ENERGY PARTICLE PRODUCTION AND RESIDUAL NUCLEI PRODUCTION FROM HIGH-ENERGY HADRON-NUCLEUS COLLISIONS

F. S. Alsmiller R. G. Alsmiller, Jr.
O. W. Hermann*

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 2, p. 444 (1987)]

The high-energy hadron-nucleus collision model, EVENTQ, developed by J. Ranft *et al.*, has been modified to include a calculation of the excitation and kinetic energy of the residual compound nucleus. The specific purpose of the modification is to make it possible to use the model in the high-energy radiation transport code, HETC, which, in conjunction with MORSE, is used to transport the low energy particles. It is assumed that the nucleons in the nucleus move in a one-dimensional potential well and have the momentum distribution of a degenerate Fermi gas. The low energy particles produced by the deexcitation of the residual compound nucleus, and the final residual nucleus, are determined from an evaporation model. Comparisons of multiplicities and residual nuclei distributions with experimental data are given. The "grey" particles, i.e., charged particles with $0.25 < \beta < 0.7$, are in good agreement with experimental data but the residual nuclei distributions are not.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

3.14

MODIFICATIONS OF THE HIGH- ENERGY TRANSPORT CODE (HETC) AND COMPARISONS WITH EXPERIMENTAL RESULTS

R. G. Alsmiller, Jr. F. S. Alsmiller
T. A. Gabriel O. W. Hermann*

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 2, p. 399 (1987)]

The High-Energy Transport Code HETC has been revised by incorporating the multi-chain fragmentation model of J. Ranft *et al.* to describe particle production from high-energy hadron-nucleus collisions. The revised code is briefly described and its validity is tested by comparing calculated results with experimental data from 29.4 GeV protons incident on an iron-air beam stop and with experimental data from 800 GeV protons incident on a large iron block. Some comparisons with calculated results obtained with other available transport codes; FLUKA82, CASIM, and MARS10 are also included.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

3.15

NUCLEON-MESON CASCADE CALCULATIONS BY MONTE CARLO METHODS

R. G. Alsmiller, Jr. F. S. Alsmiller
T. A. Gabriel O. W. Hermann*

[Abstract of Trans. Am. Nucl. Soc. 52, 385 (1986)]

The high energy transport code HETC, a Monte Carlo code developed at Oak Ridge National Laboratory, has been available for many years. For very high energy incident particles (around hundreds of gigaelectron volts), three additional Monte Carlo codes, FLUKA82,

CASIM, and MARS, have been developed and used. The major differences between the various codes are the manner in which they account for differential particle production from nucleon-nucleus and meson-nucleus collisions at high energy and the manner in which they approximate the transport of the particles in the cascade at the lower energies (≤ 3 GeV). In this paper, the various codes are compared with experimental data and with each other.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

* Computing and Telecommunications Division.

3.16

CALCULATED FRACTION OF AN INCIDENT CURRENT PULSE THAT WILL BE ACCELERATED BY AN ELECTRON LINEAR ACCELERATOR AND COMPARISONS WITH EXPERIMENTAL DATA

R. G. Alsmiller, Jr. F. S. Alsmiller
T. A. Lewis*

[Abstract of ORNL/TM-10010, May 1986; also *Nucl. Instrum. Meth. in Phys. Research A256*, 409 (1987); also *Trans. Am. Nucl. Soc.* 52, 392 (1986)]

In a series of previous papers, calculated results obtained using a one-dimensional ballistic model were presented to aid in the design of a prebuncher for the Oak Ridge Electron Linear Accelerator. As part of this work, a model was developed to provide limits on the fraction of an incident current pulse that would be accelerated by the existing accelerator. In this paper experimental data on this fraction are presented and the validity of the model developed previously is tested by comparing calculated and experimental data. Part of the experimental data is used to fix the physical parameters in the model and then good agreement between the calculated results and the rest of the experimental data is obtained.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Instrumentation and Controls Division.

3.17

NEUTRON-PHOTON MULTIGROUP CROSS SECTIONS FOR NEUTRON ENERGIES ≤ 400 MeV (REVISION 1)

R. G. Alsmiller, Jr. J. M. Barnes*
J. D. Drischler

[Abstract of ORNL/TM-9801, February 1986; also *Nucl. Instrum. Methods in Phys. Research A249*, 455 (1986); also *Trans. Am. Nucl. Soc.* 52, 638 (1986)]

Multigroup cross sections (66 neutron groups and 22 photon groups) are described for neutron energies from thermal to 400 MeV. The elements considered are hydrogen, ^{10}B , ^{11}B , carbon, nitrogen, oxygen, sodium, magnesium, aluminum, silicon, sulfur, potassium, calcium, chromium, iron, nickel, tungsten, and lead. The cross-section data presented are a revision of similar data presented previously. In the case of iron, transport calculations using the earlier and the revised cross sections are presented and compared, and significant differences are found. The revised cross sections are available from the Radiation Shielding Information Center of the Oak Ridge National Laboratory.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

* Computing and Telecommunications Division.

3.18

RADIATION DAMAGE IN SILICON DUE TO ALBEDO NEUTRONS EMITTED FROM HADRONIC BEAM DUMPS (Fe AND U)

T. A. Gabriel B. L. Bishop*

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; *Proc. Vol. 2*, p. 454 (1987)]

Calculations have been carried out to determine the level of radiation damage that can be expected from albedo neutrons when 1- and 5-GeV negative pions are incident on iron and uranium beam dumps. The calculated damage

data are presented in several ways including neutron fluence above 0.111 MeV, 1 MeV equivalent neutron fluence, damage energy deposition, and DPA or displacements per atom. Details are presented as to the method of calculation.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

3.19

RESPONSE OF A SEGMENTED LEAD GLASS CERENKOV COUNTER TO (1-10 GeV) INCIDENT ELECTRONS, GAMMA RAYS AND HADRONS

T. A. Gabriel B. L. Bishop*

(Abstract of ORNL/TM-10207, November 1986)

The response of a segmented lead glass Cerenkov counter to (1-10 GeV) incident electrons, gamma rays and hadrons is studied using the CALOR computer system. The counter is divided into 30×30 modules each with a size of $3.5 \times 3.5 \times 46 \text{ cm}^3$. The calculated quantities include module cross talk, pulse height distribution, with and without energy cuts.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

3.20

SCINTILLATION LIGHT TRANSPORT AND DETECTION

T. A. Gabriel R. A. Lillie

(Abstract of ORNL/TM-10047, August 1986; also *Nucl. Instrum. Methods in Phys. Research A258*, 242 (1987))

The MORSE neutron gamma-ray transport code has been modified to allow for the transport of scintillation light. This modified code is used to analyze the light collection characteristics of a large liquid scintillator module ($18 \times 18 \times 350 \text{ cm}^3$).

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

3.21

SHIELDING CONSIDERATIONS FOR THE 750-MeV ELECTRON ACCELERATOR AT THE UNIVERSITY OF ILLINOIS

T. A. Gabriel R. A. Lillie
B. L. Bishop*

(Abstract of ORNL/TM-10036, August 1986)

Shielding calculations for the proposed 750-MeV electron accelerator at the University of Illinois are presented and discussed.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

3.22

SHIELDING OF MANNED SPACE STATIONS AGAINST VAN ALLEN BELT PROTONS — A PRELIMINARY SCOPING STUDY

R. T. Santoro R. G. Alsmiller, Jr.
J. M. Barnes* J. M. Corbin†

(Abstract of ORNL/TM-10040, September 1986)

Calculated results are presented to aid in the design of the shielding required to protect astronauts in a space station that is orbiting through the Van Allen proton belt. The geometry considered — a spherical shell shield with a spherical tissue phantom at its center — is only a very approximate representation of an actual space station, but this simple geometry makes it possible to consider a wide range of possible shield materials. Both homogeneous and laminated shields are considered. Also, an approximation procedure — the equivalent thickness approximation — that allows dose rates to be estimated for any shield material or materials from the dose rates for an aluminum shield is presented and discussed.

Research sponsored by Martin Marietta Michoud Aerospace, New Orleans, LA.

*Computing and Telecommunications Division.

†Martin Marietta Michoud Aerospace, New Orleans, LA.

3.23

CALCULATIONS OF DOUBLE DIFFERENTIAL $^{184}\text{W}(n, xn)$ CROSS SECTIONS AT 25.7 MeV BY THE TNG CODE

C. Y. Fu D. M. Hetrick*

(Abstract of NEA Data Bank Report *Blind Intercomparison for $n + ^{184}\text{W}$ at 25.7 MeV*, NEA Data Bank, F-91191 Gif-Sur-Yvette Cedex, France)

Neutron-induced cross sections of ^{184}W at 25.7 MeV were calculated using the TNG code for participation in an international intercomparison of precompound nuclear model codes organized by the NEA data bank. Cross sections reported here include the total, elastic, nonelastic, inelastic to the 2+ and 4+ states, first neutron emission spectrum, total neutron emission spectrum, and angular distributions for outgoing neutron energies of 13.5, 15.5, 18.5, and 21.5 MeV. Reactions contributing to the total neutron spectrum are (n, n') , $(n, 2n)$, $(n, 3n)$, and $(n, 4n)$. Direct inelastic cross sections for the 2+ and 4+ states were predicted using the DWUCK code.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Computing and Telecommunications Division.

3.24

RECENT IMPROVEMENTS OF THE TNG STATISTICAL MODEL CODE

K. Shibata* C. Y. Fu

(Abstract of ORNL/TM-10093, August 1986)

The applicability of the nuclear model code TNG to cross-section evaluations has been extended. The new TNG is capable of using variable bins for outgoing particle energies. Moreover, three additional quantities can now be calculated: capture gamma-ray spectrum, the precompound mode of the (n, γ) reaction, and fission cross section. In this report, the new features of the code are described together with

some sample calculations and a brief explanation of the input data.

Research sponsored by U.S. DOE and Japan Atomic Energy Research Institute.

*Japan Atomic Energy Research Institute, Japan.

3.25

ACCELERATOR BREEDER NUCLEAR FUEL PRODUCTION: CONCEPT EVALUATION OF A MODIFIED DESIGN FOR ORNL'S PROPOSED TMF-ENFP

J. O. Johnson T. A. Gabriel
D. E. Bartine*

(Abstract of ORNL/TM-8999, July 1986)

Recent advances in accelerator beam technology have made it possible to improve the target/blanket design of the Ternary Metal Fueled Electronuclear Fuel Producer (TMF-ENFP), an accelerator-breeder design concept proposed by Burns *et al.* for subcritical breeding of the fissile isotope ^{233}U . In the original TMF-ENFP the 300-mA, 1100-MeV proton beam was limited to a small diameter whose power density was so high that a solid metal target could not be used for producing the spallation neutrons needed to drive the breeding process. Instead the target was a central column of circulating liquid sodium, which was surrounded by an inner multiplying region of ternary fuel rods (^{239}Pu , ^{232}Th , and ^{238}U) and an outer blanket region of ^{232}Th rods, with the entire system cooled by circulating sodium. In the modified design proposed here, the proton beam is sufficiently spread out to allow the ternary fuel to reside directly in the beam and to be preceded by a thin (nonstructural) V-Ti steel first wall. Thus the fuel itself acts as the target. The spread beam mandated a change in the design configuration (from a cylindrical shape to an Erlenmeyer flask shape), which, in turn, required that the fuel rods (and blanket rods) be replaced by fuel pebbles. The fuel residence time in both systems was assumed to be 90 full power days. A series of parameter optimization calculations for the modified TMF-ENFP led to a semioptimized system in which

the initial ^{239}Pu inventory of the ternary fuel was 6% and the fuel pebble diameter was 0.5 cm. With this system the ^{239}Pu production rate of 5.8 kg/day reported for the original TMF-ENFP was increased to 9.3 kg/day, and the thermal power production at beginning of cycle was increased from 3300 MW(t) to 5240 MW(t). Over the cycle length the k_{eff} of the modified TMF-ENFP decreases slightly, which provides a safety feature, and the thermal power in the modified TMF-ENFP remains essentially constant over the

cycle length, which facilitates a secondary side heat removal design. However, additional studies are needed to further optimize both the neutronic and the thermal-hydraulic performance parameters of the system. In particular, a flatter proton beam profile would alleviate radiation-damage and heat-transfer problems, which, in turn, would allow the first wall to be redesigned to serve as a structural component.

Research sponsored by U.S. Department of Energy.

*Engineering Technology Division.

Numerical Methods for Radiation Transport

3.26

A DIFFUSION THEORY MODEL FOR OPTIMIZATION CALCULATIONS OF COLD NEUTRON SOURCES

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 55, 343 (1987)]

Several optimization studies of cold sources showed the existence of an optimum thickness of the cold source that yields the maximum fraction of cold neutrons, with the optimum thickness dependent on the material used as moderator in the cold source. However, no attempt was made to explain the occurrence of the optimum thickness, especially for liquid deuterium, LD_2 . Indeed, it was suggested that LD_2 cold sources have no optimum thickness because of the very low absorption.

A simple two-group diffusion model of an infinite slab, LD_2 cold source, permits us to obtain an analytical solution from which we can deduce the reason for the optimum thickness based solely on diffusion type phenomena. It showed that even with zero absorption, increasing the slab thickness has a decreasing effect on the leakage because it reduces the flux gradient at the exit end of the slab.

This model is used to evaluate the cold neutron leakage as a function of the cold moderator thickness. The results of this calculation are about 70% lower than a two-dimensional DOT

calculation of the same configuration. A significant improvement in the results of the diffusion model is achieved by applying boundary conditions on the partial currents rather than on the flux and total current; i.e., mixed boundary conditions. The results for this more sophisticated model are about 20% higher than the transport calculation, a factor of three better than the first model. The optimum thickness, on the other hand, is well predicted by both models and is in very good agreement with the transport calculated optimum thickness.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

3.27

GENERAL ORDER NODAL TRANSPORT METHODS IN WEIGHTED DIAMOND DIFFERENCE FORM

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 55, 350 (1987)]

The bilinear (BL) nodal method for solving the neutron transport equation has been extended to general dimensionality in cartesian geometry and general order of approximation. In spite of their generality, the final discrete-variable equations have a simple compact weighted diamond difference (WDD) form in terms of a single spatial weight per dimension per distinct discrete ordinate.

The resulting equations were implemented in a computer code that produces an arbitrary order numerical solution of steady state, monoenergetic, isotropic scattering, external source, discrete ordinates transport problems in two-dimensional cartesian geometry. As a numerical example of our general order implementation of nodal transport methods, we solved a simple, previously considered test problem, using approximation orders ranging from 0 to 9.

Our results suggest that up to order 5, the performance (smaller storage and shorter CPU time) monotonically improves. Hence, very high-order methods may be of practical interest in solving realistic problems with large homogeneous regions, and of academic interest for their importance in calculating very accurate solutions to benchmark problems.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

3.28

THE BILINEAR NODAL TRANSPORT METHOD IN WEIGHTED DIAMOND DIFFERENCE FORM

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 54, 187 (1987)]

In this paper we outline the development of an analytic linear-linear nodal method, the bilinear method, which can be written in a weighted diamond difference (WDD) form with one spatial weight per dimension that is analytically derived rather than preassigned in an *ad hoc* fashion.

The resulting equation is a generalization of the WDD equation to include a linear spatial component of the flux in addition to the constant component present in conventional WDD schemes. Moreover, it is an analytic LL nodal method, even though it has a simpler form than existing PLL schemes, which permits using a WDD algorithm to solve the discrete variable equations. Also, it requires the storage of only one parameter, α_n , per node, per dimension, per distinct discrete ordinate, compared to a larger storage requirement even in current PLL methods.

In order to verify the derivation of our method, we implemented our equations in a computer program and used it to solve a one-group version of the well-logging problem. The average flux in the detector as calculated by the bilinear method is compared to that calculated by other nodal methods as well as to the h^2 -extrapolated value. The comparison indicates the correctness and very high accuracy of our bilinear nodal method.

Research sponsored by U.S. Department of Energy and by University of Virginia, Charlottesville, VA.

3.29

A NODAL INTEGRAL METHOD FOR THE NEUTRON DIFFUSION EQUATION IN CYLINDRICAL GEOMETRY

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 54, 183 (1987)]

In this paper we report recent progress in deriving and numerically implementing a nodal integral method (NIM) for solving the neutron diffusion equation in cylindrical r - z geometry. The derivation is an extension of the general nodal integral approach previously developed for deriving nodal methods for linear partial differential equations in cartesian geometry. The main difference is the weight function r applied in performing the transverse-integration in the radial direction, while the z -transverse averaging operator is defined exactly as in Cartesian geometry.

We have coded the discrete variable equations into a computer program. In order to evaluate the performance of our new numerical method, it is applied to two test problems and the results are compared with those of a finite difference code, EXTERMINATOR-2. These indicate the superior accuracy of the nodal integral method solutions on much coarser meshes. This demonstrates that it is possible to develop nodal methods for partial differential equations in cylindrical geometry that have many attractive features similar to those displayed by their Cartesian geometry counterparts.

Research sponsored by U.S. Department of Energy and by University of Virginia, Charlottesville, VA.

3.30

THE WEIGHTED DIAMOND DIFFERENCE FORM OF NODAL TRANSPORT METHODS

Y. Y. Azmy

[Abstract of *Nucl. Sci. Eng.* (in press)]

Very high computational efficiencies have been achieved recently by introducing higher order approximations to nodal formalisms for the discrete ordinates, neutron transport equation. However, the difficulty of the nodal formalism, its final discrete variable equations, and the solution algorithms have limited the usefulness and applicability of Nodal Methods in spite of their extremely high accuracy.

In this paper we derive a general-order, general-dimensionality nodal transport method cast in a simple, compact, single-weight, weighted diamond difference form. The new form is a consistently formulated nodal method, which can be solved using either the DNTM or the NEFD algorithms without any approximations. The final discrete variable equations for the two-dimensional case are implemented in a computer code to solve monoenergetic, isotropic scattering, external source problems to any given order, i.e., C-C, L-L, Q-Q, etc. We solve a simple test problem with large homogeneous regions using this code on meshes ranging from 2×2 to 128×128 and orders ranging from zero to nine. The results show that, for this problem, the CPU time and the storage size required to achieve a given accuracy decrease monotonically up to order five. Hence, very high order methods may be more computationally efficient in solving practical problems with large homogeneous regions.

Research sponsored by U.S. Department of Energy.

3.31

MULTIDIMENSIONAL LINEAR-LINEAR NODAL TRANSPORT METHODS IN WEIGHTED DIAMOND DIFFERENCE FORM

Y. Y. Azmy

[Abstract of *Nucl. Sci. Eng.* (in press); also paper presented at the International Topical Meeting on Advances in Reactor Physics, Mathematics and Computation, Paris, France, April 27-30, 1987]

Two previously derived approximations to the linear-linear nodal transport method, the linear nodal (LN) and the linear linear (LL) methods, are re-examined together with a new approximation, the bi-linear (BL) method, that takes into account the bilinear nodal flux-moment. The three methods differ in the degree of analyticity retained in the final discrete-variable equations; however, they all possess the very high accuracy characteristic of nodal methods. Unlike previous work, here the final equations are manipulated and cast in the form of the classical weighted diamond difference (WDD) equations (not just a WDD algorithm). This makes them simple to implement in a computer code, especially for those users who have experience with WDD algorithms. Other algorithms, such as the nodal algorithm, also can be used to solve the WDD-form equations.

A computer program that solves two-dimensional transport problems using the LN, LL, or the BL method is used to solve three test problems. The results are used here to confirm our algebraic manipulations of the nodal equations and also to compare the performance of the three methods from the computational, as well as the theoretical, point of view. The three methods are found to have comparable accuracies for the problems studied, especially on meshes that are sufficiently fine.

Research sponsored by U.S. Department of Energy.

3.32

THE LINEAR CHARACTERISTIC METHOD IN XYZ GEOMETRY

R. L. Childs* W. A. Rhoades

[Abstract of *Trans. Am. Nucl. Soc.* 55, 352 (1987)]

Recent studies of the linear nodal method of solving the S_n transport equations have lead to renewed interest in characteristic methods. Although the methods are closely related in principle, they differ in detail and effectiveness. In particular, constraints required to assure positive results limit the accuracy of the nodal method. The characteristic method proved superior in the demonstration cases studied.

Research sponsored by U.S. Department of Energy.

*Computing and Telecommunications Division.

3.33

USER'S MANUAL FOR PUTZ: A POINT-KERNEL PHOTON SHIELDING CODE

D. T. Ingersoll

(Abstract of ORNL/TM-9803, May 1986)

A photon shielding code based on the point-kernel method has been developed. The code, entitled PUTZ, allows the specification of three-dimensional source and body geometries using simple parallelepipeds and annular parallelepipeds, and permits the inclusion of multiple sources and multiple detectors in a single case. A flexible free-form type input format is used, and attenuation data and material buildup factors are contained within the code for selected materials. Versions of the code are available for running on an IBM mainframe computer and an IBM-PC microcomputer (or compatible). A comprehensive user's manual is provided, which describes the basic algorithms, input requirements, output listings, and major limitations.

Research sponsored by U.S. DOE Consolidated Fuel Reprocessing Program.

3.34

VERIFICATION OF A MONTE CARLO CODE SYSTEM FOR ANALYSIS OF IONIZATION CHAMBER RESPONSES

J. O. Johnson T. A. Gabriel

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 1, p. 110 (1987)]

The purpose of this work was the development and testing of a Monte Carlo code system for calculating an ionization chamber response to a mixed neutron and photon radiation environment. The resulting code system entitled MICAP — a Monte Carlo Ionization Chamber Analysis Package — determines the neutron, photon, and total response of the ionization chamber to the mixed field radiation environment. To demonstrate the ability of MICAP, comparisons were made with existing code systems and experimental results. Comparisons with existing code systems verified the accuracy of the neutron, photon, and charged particle transport processes and the nuclear models used to describe the individual neutron reactions. Comparisons with mono-energetic photon calibration experiments and mixed neutron and photon radiation experiments verified the applicability of MICAP for analysis of ionization chamber responses to mixed field radiation environments. The major conclusion of the study is that MICAP represents a unique capability in the area of ionization chamber response analysis and is expected to be useful for many applications in the field of radiation dosimetry.

Research sponsored by U.S. DOE Liquid Metal Converter Reactor Program.

3.35

DEVELOPMENT AND TESTING OF A MONTE CARLO CODE SYSTEM FOR ANALYSIS OF IONIZATION CHAMBER RESPONSES

J. O. Johnson T. A. Gabriel

[Abstract of *Trans. Am. Nucl. Soc.* 53, 408 (1966)]

A differential Monte Carlo computer code system entitled MICAP (*Monte Carlo Ionization Chamber Analysis Package*) was developed and tested at Oak Ridge National Laboratory for determining the neutron, photon, and total response of an ionization chamber to mixed-field radiation environments. The calculational scheme used in MICAP follows histories of the radiation incident on the ionization chamber wall material. The incident neutron radiation produces photons and charged particles (protons, alpha particles, recoil heavy ions, etc.), and both primary and secondary photons produce electrons. As these charged particles and electrons enter or are produced in the chamber cavity material, they lose energy and produce ion pairs until their energy is completely dissipated or they escape the cavity. The ability of MICAP in calculating an ionization chamber response was demonstrated through comparisons to existing code systems and experimental data. Preliminary comparisons of pulse-height distributions generated in MICAP and OSS — an established Monte Carlo code used extensively to accurately calibrate liquid organic scintillators — showed excellent agreement. Furthermore, MICAP results agreed to within 6% of the experimental results for the photon calibration experiments of the Armed Forces Radiobiology Research Institute 50 cm³ ionization chambers and to within 8% of the Health and Safety Laboratory photon calibration experiments of the high pressure argon ionization chamber system used in the measurement of environmental exposure rates. This new code system represents a unique capability in the area of ionization chamber response analysis and is expected to be useful for many applications in the field of radiation dosimetry.

Research sponsored by Defense Nuclear Agency.

3.36

DEVELOPMENT AND EVALUATION OF A MONTE CARLO CODE SYSTEM FOR ANALYSIS OF IONIZATION CHAMBER RESPONSES

J. O. Johnson T. A. Gabriel

(Abstract of ORNL/TM-10196, July 1967; also J. O. Johnson's Dissertation for the Doctor of Philosophy Degree, University of Tennessee, Knoxville, TN, June 1967)

The purpose of this work is the development and testing of a Monte Carlo code system for calculating the response of an ionization chamber to a mixed neutron and photon radiation environment. The resulting code system entitled MICAP — a *Monte Carlo Ionization Chamber Analysis Package* — determines the neutron, photon, and total responses of the ionization chamber to the mixed field radiation environment. The Monte Carlo method performs accurate simulations of the physical processes involved in detecting radiation using ionization chambers, and eliminates limitations inherent in approximate methods.

The calculational scheme used in MICAP follows individual radiation particles incident on the ionization chamber wall material. The incident neutrons produce photons and heavy charged particles and both primary and secondary photons produce electrons and positrons. As these charged particles enter or are produced in the chamber cavity material, they lose energy and produce ion pairs until their energy is completely dissipated or until they escape the cavity. Ion recombination effects are included along the path of each charged particle rather than applied as an integral correction to the final result. ENDF/B-V partial cross section data have been incorporated in the neutron transport module to account for all processes which may contribute to the output signal. The transport modules utilize continuous angular distribution and secondary energy distribution data when selecting the emergent direction and energy of a particle. Furthermore, reactions are treated as discrete and allowed to occur with any of the constituent nuclides comprising a mixture. Finally, MICAP incorporates a combinatorial geometry package and input cross section processors to eliminate

restrictions in the modeling capability of the code system with respect to geometry, physical processes, nuclear data, and sources.

To evaluate MICAP, comparisons were made with results obtained using other code systems and with experimental results. Separate comparisons with other code systems verified the validity of the neutron, photon, and charged particle transport processes and the nuclear models used to describe the individual neutron reactions, respectively. Comparisons with mono-energetic photon calibration experiments and with mixed neutron and photon radiation experiments verified the applicability of MICAP for analyzing the response of ionization chambers to mixed field radiation environments.

Research sponsored by Defense Nuclear Agency.

3.37

S_n TRANSPORT CALCULATIONS ON VECTOR AND PARALLEL PROCESSORS

W. A. Rhodes R. L. Childs*

[Abstract of *Trans. Am. Nucl. Soc.* 55, 320 (1987)]

Beginning in 1982, a thorough revision of the DOT 2-D S_n transport code brought efficient operation on modern vector computers. The updated code, called DORT, shares many subroutines with its 3-D companion, TORT. This paper discusses the various techniques required to vectorize four major sections of the coding. The prospects for adaptation to newer computer architectures are discussed.

Research sponsored by Defense Nuclear Agency.

3.38

THE TORT THREE-DIMENSIONAL DISCRETE ORDINATES NEUTRON/PHOTON TRANSPORT CODE

W. A. Rhodes R. L. Childs*

(Abstract of ORNL-6268, November 1987)

TORT is designed to solve very large two- or three-dimensional neutron and/or photon trans-

port problems on a Cray or comparable computer using the method of discrete ordinates. Extensive adaptability to new systems has been provided. Several flux solution procedures and acceleration methods are provided. The code can be used in stand-alone mode or under control of a driver.

Problem specification requirements are similar to those of the DOT code, but are simpler and more convenient. The new zone specification format can be converted to a combinatorial geometry form for use in Monte Carlo codes. Several applications papers and a benchmark experiment relating to TORT have been produced.

Research sponsored by Defense Nuclear Agency.

* Computing and Telecommunications Division.

3.39

VERIFICATION EXPERIMENT OF THE THREE-DIMENSIONAL OAK RIDGE TRANSPORT CODE (TORT)

F. J. Muckenthaler L. B. Holland*
J. L. Hall*

(Abstract of ORNL/TM-9528, December 1985)

An experiment was conducted at the Oak Ridge National Laboratory Tower Shielding Facility during FY 1984-85 to provide verification of a discrete ordinates Three-dimensional Oak Ridge Transport computer code (TORT), which is being developed at ORNL for calculating the neutron and gamma-ray fluxes within concrete structures that were exposed to radiation at Hiroshima and Nagasaki. In the experiment a collimated beam of radiation from the Tower Shielding Reactor II, modified to represent the spectra of neutrons and gamma rays emitted in weapons bursts, impinged on a concrete structure simulating a small, simple, single-story concrete block house. Variations in the structure were introduced during the experiment by successive changes in the outer wall and within the building: several blocks in the front wall were removed to form a window; a concrete support pillar within the building was relocated; and a central concrete

wall was added to divide the single room into two rooms of approximately the same dimensions. Integral neutron fluxes and gamma-ray energy depositions were measured both in the modified reactor beam and at selected locations inside each structure. This report describes the experiment and presents the detailed results in both tabular and graphical form. It also discusses the impact of the variations in the basic configuration on the measured results.

Research sponsored by the Defense Nuclear Agency.

*Operations Division.

3.40

DEVELOPMENT AND EVALUATION OF DOTTOR, A COMPUTER CODE TO COUPLE TWO-DIMENSIONAL TO THREE-DIMENSIONAL DISCRETE ORDINATES CALCULATIONS

J. L. Thompson* M. B. Emmett†
H. L. Dodds, Jr.*

(Abstract of ORNL/TM-9919, April 1986; also J. L. Thompson's thesis for Master of Science Degree, University of Tennessee, December 1985)

A method has been developed to couple two-dimensional (2-D) to three-dimensional (3-D) discrete ordinates transport calculations. This method is useful for problems in which a 3-D Cartesian (X-Y-Z geometry) region of interest is very far from a point source. A 3-D solution from the source including the region of interest is prohibited due to the large computing cost of such calculations.

The problem is solved by first performing a 2-D discrete ordinates calculation from the source past the region of interest. The results of the 2-D calculations are transformed into a boundary condition on the surface of the 3-D region of interest. This transformation or coupling method is developed and implemented in the DOTTOR computer code. The boundary condition is then used for a subsequent 3-D discrete ordinates calculation in the region of interest.

Simple test problems were used to evaluate the accuracy and speed (i.e., computing cost) of the DOTTOR code. The evaluation indicates

that the DOTTOR code produces accurate results with acceptable computing costs. The algorithm chosen showed a significant speed advantage over others tested when applied to large problems.

Research sponsored by Defense Nuclear Agency.

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†Computing and Telecommunications Division.

3.41

A DISCUSSION ABOUT MODELING THE EFFECTS OF NEUTRON FLUX EXPOSURE FOR NUCLEAR REACTOR CORE ANALYSIS

D. R. Vondy

(Abstract of ORNL/TM-9860, April 1986)

Methods used to calculate the effects of exposure to a neutron flux are described. The modeling of a nuclear reactor-core history presents an analysis challenge. The nuclide chain equations must be solved, and some of the methods in use for this are described. Techniques for treating reactor-core histories are discussed and evaluated.

Research sponsored by U.S. Department of Energy.

3.42

TWO-DIMENSIONAL ELECTRON TRANSPORT CALCULATIONS USING THE STREAMING RAY METHOD

M. S. Smith W. L. Filippone*

[Abstract of *Trans. Am. Nucl. Soc.* 55, 361 (1987)]

The method of streaming rays (SR) has been shown previously to be an effective algorithm for one-dimensional electron transport studies. The Spencer-Lewis equation is solved for the electron distribution in phase space; electrons are followed as they traverse the medium along specified streaming rays and fluxes are computed at the centers of the fixed cells. In this work, the method of streaming rays has been expended to two spatial dimensions (three phase space dimensions, x , y , and s) and was used as a basis for the

development of the electron transport computer code SR2D. The development of the SR2D code required the specification of a Lagrangian streaming ray network overlaying a three-dimensional Eulerian grid. The critical aspect of the streaming ray method is the determination of the pathlengths of each and every streaming ray through all of the Eulerian cells. These values must be precalculated and stored because of the

iterative nature of the solution scheme. To validate the SR2D results, a test problem was solved using the electron/photon Monte Carlo code TIGER and SR2D. For this problem, the calculated values of the total energy deposited were within 1%, but peak cell energies varied by 4%.

Research sponsored by U.S. DOE and U.S. Air Force.

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Theoretical Investigations of the Boltzmann Equation

3.43

TRANSPORT EQUATIONS WITH SECOND ORDER DIFFERENTIAL COLLISION OPERATORS

C. Cosner* S. M. Lenhart†
V. Protopenescu

[Abstract of *SIAM J. Math. Anal.* (in press)]

This paper discusses existence, uniqueness and *a priori* estimates for time dependent and time independent transport equations with unbounded collision operators. These collision operators are second order differential operators that describe diffusion in the velocity space. The transport equations are degenerate parabolic-elliptic partial differential equations, which are treated by modifications of the Fichera-Oleinik-Radkevich theory of second order equations with non-negative characteristic form. We consider weak solutions in spaces which are extensions of L^p to include traces on certain parts of the boundary. This extension is necessary due to the non-classical boundary conditions imposed from the transport problem, which requires a careful analysis of the behavior of our weak solutions.

Research partially sponsored by U.S. Department of Energy.

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3.44

TRANSPORT EQUATIONS WITH BOUNDARY CONDITIONS OF REVERSE REFLECTION TYPE

G. Frosali* C. V. M. van der Meer*
V. Protopenescu

[Abstract of *Math. Meth. in Appl. Sciences* (in press)]

A study is performed of transport equations on arbitrary three-dimensional domains with boundary conditions of reverse reflection type. The existence of the dominant eigenvalue of the criticality problem is proved and its independence of the functional setting and its continuous dependence on a variety of data are established. The corresponding time-dependent problem is shown to be well-posed, also for a conservative boundary. The relationship between the criticality and the time-dependent problem is given explicitly.

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3.45

CAN THE MIXED NORM BE USED IN KINETIC THEORY?

G. Frosali* V. Protopenescu

[Abstract of *Bulletino Unione Matematica Italiana* (in press)]

In this paper we discuss the possibility of using a mixed norm to existence problems in

kinetic theory. In this context, we prove that the shift operator is unbounded in the space $L_\infty(\mathbb{R}^3)$ $L_1(\mathbb{R}^3)$ which is the most meaningful from the physical viewpoint. Finally, we consider the application of mixed norms to criticality problems.

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3.46

BOUNDARY VALUE PROBLEMS IN ABSTRACT KINETIC THEORY

W. Greenberg* C. V. M. van der Mee*
V. Protopopescu

[Abstract of Book, Vol. 23 of Series Operator Theory: Advances and Applications, Birkhäuser Verlag, Publisher (1987)]

This monograph presents a rigorous exposition of boundary value problems related to kinetic equations. Such equations are of fundamental importance in describing the transport of mass and energy in many areas of physics, chemistry, biology and engineering, and in modeling phenomena from more diverse areas, such as economics, sociology and informatics. Mathematical problems are addressed dealing with existence and uniqueness of solutions of initial-boundary value problems, as well as questions of positivity, continuity, growth, stability and explicit representation of solutions. A strenuous effort has been made to separate the abstract theory from the various applications, which are cross-referenced throughout the text. In fact, three chapters, including the longest in the monograph, are devoted entirely to applications. Detailed examples are drawn from a large variety of sub-disciplines, ranging from radiative transfer and transport in crystals, to diffusion theory and cell biology.

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3.47

GLOBAL EXISTENCE FOR A MODEL BOLTZMANN EQUATION

V. Protopopescu

[Abstract of *Phys. Lett. A* (in press)]

We give a global existence proof for a class of inhomogeneous continuous velocity Boltzmann models with stochastic scattering kernels.

Research partially sponsored by U.S. DOE Office of Joint Chiefs of Staff.

3.48

ON THE FOKKER-PLANCK EQUATION WITH FORCE TERM

V. Protopopescu

[Abstract of *J. Phys. A* (in press)]

We show that half-range completeness and half-range orthogonality relations hold for the stationary one-dimensional Fokker-Planck transport problem for some velocity dependent external forces and general boundary conditions.

Research partially sponsored by U.S. Department of Energy and U.S. Department of Defense.

3.49

THE SPECTRAL DECOMPOSITION OF THE LINEARIZED VLASOV-POISSON OPERATOR

V. Protopopescu

[Abstract of *Comptes Rendus de l'Académie Paris* 302, Série I, 271 (1986)]

One proves that the linearized Vlasov-Poisson operator allows for a spectral decomposition, which permits to write the solution of the associated transport problem in terms of the true resolvent and its poles (eigenvalues of the operator) instead of its analytic extension and pseudo-poles (resonances).

3.50

**THE NONLINEAR BOLTZMANN
EQUATION WITH PARTIALLY
ABSORBING BOUNDARY CONDITIONS.
GLOBAL EXISTENCE AND
UNIQUENESS RESULTS**

G. Toscani* V. Protopopescu

[Abstract of *J. Math. Phys.* 28, 1140 (1986)]

We generalize the method applied by Bellomo and Toscani for the Boltzmann equation in an infinite medium to establish global results for bounded media with partially absorbing boundary conditions. The method requires that the equilibrium solution be the vacuum state and, accordingly, relies on positivity/monotonicity arguments. The growth produced by the nonlinearity is compensated by the combined effect of streaming and (partial) absorption (leakage) at the boundary.

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3.51

**GLOBAL EXISTENCE FOR A MIXED
PROBLEM ASSOCIATED WITH THE
NONLINEAR BOLTZMANN EQUATION**

G. Toscani* V. Protopopescu

[Abstract of *Comptes Rendus de l'Académie Paris* 302, Série I, 255 (1986)]

By generalizing the method used by N. Bellomo and G. Toscani for an infinite medium, we obtain global existence results for the nonlinear Boltzmann equation in media with partially periodic or partially reflecting walls.

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Nuclear Weapons Effects

3.52

**SENSITIVITY/UNCERTAINTY ANALYSIS
FOR THE HIROSHIMA DOSIMETRY
REEVALUATION EFFORT**

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J. V. Pace, III* D. G. Cacuci**

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 1, p. 149 (1987)]

Uncertainty estimates and cross correlations by range/survivor location have been obtained for the free-in-air (FIA) tissue kerma for the Hiroshima atomic event. These uncertainties in the FIA kerma include contributions due to various modeling parameters and the basic cross-section data and are given at three ground ranges, 700, 1000, and 15 m. The estimated uncertainties are nearly constant over the given

ground ranges and are approximately 27% for the prompt neutron kerma and secondary gamma kerma and 35% for the prompt gamma kerma. The total kerma uncertainty is dominated by the secondary gamma kerma uncertainties which are in turn largely due to the modeling parameter uncertainties.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

Computing and Telecommunications Division.

3.53

SENSITIVITY/UNCERTAINTY ANALYSIS FOR THE NAGASAKI DOSIMETRY REEVALUATION EFFORT

R. A. Lillie B. L. Broadhead*
J. V. Pace, III* D. G. Cacuci

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 1, p. 139 (1987)]

Uncertainties have been calculated for the Nagasaki free-in-air (FIA) tissue kerma obtained from two-dimensional air-over-ground (A/G) transport calculations. The uncertainties due to modeling parameter and basic nuclear transport data uncertainties were calculated for ground ranges of 700, 1000, and 1500 m. Uncertainties of approximately 20% were obtained for the prompt neutron and secondary gamma kerma and 30% for the prompt gamma kerma. In general, the uncertainties are dominated by the modeling parameter uncertainties, particularly those associated with the weapon yield and radiation sources.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

*Computing and Telecommunications Division.

3.54

THE NAGASAKI REINFORCED CONCRETE BUILDING DOSE CALCULATIONS

W. A. Rhodes

(Abstract of oral presentation given at the Defense Nuclear Agency Workshop on the LD₅₀ for Healthy Young Adults Actively Irradiated with Low-LET Whole-Body Radiation, Alexandria, VA, March 9-10, 1987)

The effects of radiation on personnel inside concrete buildings during the World War II nuclear attacks is an important resource of human response information. The exposure inside two buildings at Nagasaki was calculated using state-of-the-art techniques. In one building, the external dose of 9,000 cGr was reduced to 2,200 cGr at a location near a window facing the

weapon and 170 cGr deep inside the building. A preliminary correlation of dose vs. effect shows the results to be in general agreement with expected mortality values. A detailed uncertainty analysis was performed.

Research sponsored by U.S. DOE Liquid Metal Converter Reactor Program.

3.55

DECAY RATE OF γ RADIATION FROM NUCLEAR WEAPONS FALLOUT

C. M. Hasland

[Abstract of *Health Phys.* 53(3), 313 (1987)]

"Standard decay" of fallout gamma radiation is widely assumed to be approximated by $t^{-1.2}$, but the theoretical basis for the approximation, the Way-Wigner work of 1948, actually indicates that $t^{-1.36}$ would be a better approximation. The Way-Wigner approximation for the absorbable energy (from betas and gammas) liberated per unit time from fission products is $0.1t^{-1.2} + 0.9t^{-1.4}$ when normalized to unity at unit time. Measurements of fallout gamma radiation decay for the thermonuclear shots BRAVO and UNION and for the fission shot PRISCILLA show a $t^{-1.4}$ dependency, agreeing well with the actual Way-Wigner approximation. Recent calculations by Hicks for fallout gamma radiation decay are not approximated well by any single simple expression. Measurements of the fallout gamma decay for the fission shots DIABLO and SHASTA show a $t^{-1.12}$ decay.

Research sponsored jointly by U.S. Department of Energy and Federal Emergency Management Agency.

3.56

FORECASTING RADIATION RATES AND EXPOSURE FROM MULTI-AGED FALLOUT

C. M. Hasland

[Abstract of *Health Phys. J.* (in press)]

A graphical method for forecasting radiation rates from multi-aged fallout is extended to incorporate a nomogram for forecasting radiation rates

and a simple method for forecasting accumulated radiation exposure. It is shown that the method can provide estimates of radiation rates or exposures for days to weeks in the future to within 30% from assumed actual radiation rates or exposures for fallout that decays according to t^{-n} where n is any number from 0.9 to 1.5. Because of the self-adjusting feature of the method which results in an estimated effective age for the fallout, it is not necessary to attempt to subtract contributions from separate fallouts with different ages. The method can be applied to composite fallout without knowledge of the previous history of the various-aged contributions.

Research sponsored by the Federal Emergency Management Agency.

3.57

VALIDITY OF THE $t^{-1.2}$ DECAY APPROXIMATION FOR FALLOUT GAMMA RADIATION

C. M. Haaland

(Abstract of paper presented at the 52nd Meeting of the Southeastern Section of the American Physical Society, Athens, GA, December 2-4, 1985)

The Way-Wigner approximation for radiation decay of fission products is compared with recent detailed calculations which have been empirically fit with an eleven-term decay function. When the radiation-rate sampling method is used, as described in this paper, the simple $t^{-1.2}$ approximation remains a valid simplification for forecasting radiation-rate levels and radiation exposures from fallout even when the actual decay rate may vary between $t^{-1.4}$ and $t^{-1.1}$. The radiation-rate sampling method applies for multi-aged fallout and does not rely upon knowledge of the age of the fallout.

Research sponsored jointly by the Federal Emergency Management Agency and U.S. Department of Energy.

Design of the Advanced Neutron Source Reactor

3.58

CORE PHYSICS OF THE CNR REACTOR

F. C. Difilippo

[Abstract of *Trans. Am. Nucl. Soc.* 52, 646 (1986)]

The need for a new generation of steady neutron sources has been the subject of several studies. The goal is to obtain a thermal neutron flux for scattering experiments between 5 to 10 times 10^{15} $n/cm^2 \cdot s$. Ideally, the reactor would have a core life of at least two weeks, and it would also be used to irradiate materials and produce isotopes. This paper describes the criteria and calculations related to the preliminary design of the reactor of the proposed Center for Neutron Research (CNR). The goal for the thermal neutron flux means a factor of 6 increase with respect to two existing facilities: the High Flux Isotope Reactor (HFIR) at Oak Ridge National

Laboratory and the Institute Laue-Langevin reactor (ILL) at Grenoble, France. Thus higher efficiencies in terms of thermal neutron flux per unit power are then required in order to reduce high power requirements.

Analytical studies associated with the slowing down and diffusion of neutrons produced by an extended fission source immersed in a moderator show that the efficiency can be parameterized as a function of the core volume (V_c) and of the Fermi age and diffusion length of thermal neutrons in the core (τ_c and L_c) and reflector (τ_r and L_r). The use of a low absorbing reflector, i.e., D_2O or beryllium, fixes τ_r and L_r , leaving V_c , τ_c , and L_c as the only free parameters in the design. The efficiency increases monotonically by reducing V_c and by increasing τ_c and L_c . High efficiencies are then obtained by reducing the core volume [i.e., increasing the power density (ρ)], by increasing the escape of fast neutrons from the core to the reflector (i.e., using a less efficient

moderator like D_2O), and by reducing the core life (i.e., reducing the loading).

Approximately 200 MW can be saved if we can increase the average power density from 2 MW/l (present HFIR) to 8 MW/l. Thermal-hydraulic studies show that such high power densities might be possible if corrosion problems associated with the formation of aluminum oxide on the cladding can be solved.

Based on the previous discussion, a candidate design for the CNR reactor was found. The axial length is a compromise between the extension of the thermal neutron flux peak in the axial direction and the pressure drop across the core. Axial and radial fuel grading are necessary in order to keep the relative power distribution within reasonable limits as functions of burnup. The grading was obtained by a constrained iterative optimization process as function of burnup. In conclusion, the conditions to produce unprecedented high thermal neutron fluxes with reasonable power requirements have been analyzed quantitatively.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

3.59

DESIGNING CNR, A VERY HIGH THERMAL NEUTRON FLUX FACILITY

F. C. Difilippo

[Abstract of paper presented at the American Nuclear Society National Topical Conference on Reactor Physics and Safety, Saratoga Springs, NY, September 17-19, 1986; Proc. NUREG/CP-0080, Vol. 2, p. 810 (1986)]

According to a recent study (Eastman-Seitz Committee, National Academy of Science) there is a need for a new generation of steady neutron sources with a thermal neutron flux peak between 5 to 10 times $10^{15}/\text{cm}^2 \text{ sec}$. Ideally the neutron source would have to operate continuously for several days (two weeks at least) with minimum time (2-3 days) for refueling and/or maintenance and it would also be used to irradiate materials and produce isotopes. This paper describes the preliminary design of the nuclear reactor for the

proposed Center for Neutron Research (CNR). A duplication of existing designs [HFIR, (ORNL), ILL (Grenoble, France)] would imply high total power and small core life; the necessity of higher efficiencies (in terms of peak-flux-per-unit source or power) then becomes apparent. We have found analytical expressions for the efficiency in terms of a few parameters such as the volume of the source and the Fermi age and diffusion length of thermal neutrons in both the source and reflector regions. A single analytical expression can then be used for scoping the design and to intercompare radically different designs. Higher efficiencies can be achieved by reducing the volume and the moderation of a core immersed in a very low absorbing reflector; on the contrary a very long core life has a negative effect on the efficiency at beginning of life. Consequently, and after detailed calculations, we have found a candidate design with the following characteristics: core, U_3Si_2 , 93% enriched, 18.1-kg ^{235}U , metal fraction 50%, Al cladding, and 35-L volume; reflector and moderator, D_2O ; efficiency at end of life (EOL) with respect to the ILL reactor, 1.29; flux at EOL, $10 \times 10^{15}/\text{cm}^2 \text{ sec}$ (power in core 270. MW); core life, 14 days; burnup 28.4%.

Research sponsored by U.S. DOE Division of Materials Sciences.

3.60

AN INTENSE STEADY STATE NEUTRON SOURCE — THE CNR REACTOR

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W. R. Gambill R. T. Primm, III
C. D. West'

[Abstract of paper presented at the American Nuclear Society National Topical Conference on Reactor Physics and Safety, Saratoga Springs, NY, September 17-19, 1986; Proc. NUREG/CP-0080, Vol. 2, p. 792 (1986)]

The Center for Neutron Research (CNR) has been proposed in response to the needs neutron flux, spectrum, and experimental facilities that have been identified by the neutron scattering, isotope, and materials irradiation research

communities through workshops, studies, and discussions. The CNR is a major new experimental facility consisting of a reactor-based steady state neutron source of unprecedented flux, together with extensive facilities and instruments for neu-

tron scattering, isotope production, materials irradiation, and other research areas.

Research sponsored by U.S. Department of Energy.

*Solid State Division.

†Engineering Technology Division.

Pressurized Thermal Shock

3.61

PRELIMINARY DEVELOPMENT OF AN INTEGRATED APPROACH TO THE EVALUATION OF PRESSURIZED THERMAL SHOCK AS APPLIED TO THE OCONEE UNIT 1 NUCLEAR POWER PLANT

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R. Olson†

[Abstract of ORNL/TM-9176 (NUREG/CR-3770), May 1986]

An evaluation of the risk to the Oconee-1 nuclear plant due to pressurized thermal shock (PTS) has been completed by Oak Ridge National Laboratory (ORNL). This evaluation was part of a Nuclear Regulatory Commission (NRC) program designed to study the PTS risk to three nuclear plants: Oconee-1, a Babcock and Wilcox reactor plant owned and operated by Duke Power Company; Calvert Cliffs-1, a Combustion Engineering reactor plant owned and operated by Baltimore Gas and Electric Company; and H. B. Robinson-2, a Westinghouse reactor plant owned and operated by Carolina Power and Light Company. Studies of Calvert Cliffs-1 and H. B. Robinson-2 are still underway.

The specific objectives of the Oconee-1 study were to: (1) provide a best estimate of the probability of a through-the-wall crack (TWC) occurring in the reactor pressure vessel as a result of PTS; (2) determine dominant accident sequences, plant features, operator and control actions and uncertainty in the PTS risk; and (3) evaluate effectiveness of potential corrective measures. To perform the studies, ORNL constructed millions of hypothetical overcooling events (using computer-generated event trees) and then

estimated both the consequences and the probabilities of occurrence for each of these events. A screening frequency of 10^{-6} per reactor year was used to screen out those event tree branches (scenarios) whose frequencies were below that value. All of the remaining scenarios were considered explicitly. The scenarios initially screened out were not discarded but rather were included in a residual category, and their probability contributions were included in the study. Detailed thermal-hydraulic (T-H) analyses were performed on a few of the scenarios by Los Alamos National Laboratory and Idaho National Engineering Laboratory and these were reviewed by Brookhaven National Laboratory. For some transients, downcomer mixing calculations were performed by Purdue University. Thermal-hydraulic consequences of all remaining transients (including as one group all those in the residual) were estimated by Science Applications International Corp. For all transients, probabilistic fracture-mechanics calculations were performed by ORNL. The results of all these analyses were integrated by ORNL to predict the probability of TWC for Oconee-1.

Our best estimate of the frequency of a TWC at Oconee-1 due to PTS at 32 EFPY was 4.5×10^{-6} /reactor year. However, an uncertainty analysis performed by ORNL for this best-estimate frequency indicates that a factor of about 100 is an appropriate 95% confidence interval, assuming a log-normal uncertainty distribution. Steamline breaks were the most significant contributors to the TWC risk for the types of sequences considered. Uncertainty in downcomer temperatures was the most important contributor to the overall uncertainty in the risk. The most important plant features which were determined to reduce PTS risk at Oconee-1 were: (1) internal vent valves and (2) feedwater pump trip on

high steam generator level. The most important operator action for negating PTS was the isolation of a steam generator during a steamline break.

Minimal systems interactions were considered in this study and no external events (fire, floods, seismic events) were considered.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations, Office of Nuclear Regulatory Research.

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3.62

PRESSURIZED THERMAL SHOCK EVALUATION OF THE CALVERT CLIFFS UNIT 1 NUCLEAR POWER PLANT

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[Abstract of ORNL/TM-9408 (NUREG/CR-4022), September 1985]

An evaluation of the risk to the Calvert Cliffs Unit 1 nuclear power plant due to pressurized thermal shock (PTS) has been completed by Oak Ridge National Laboratory (ORNL) with the assistance of several other organizations. This evaluation was part of a Nuclear Regulatory Commission program designed to study the PTS risk to three nuclear plants, the other two plants being Oconee Unit 1 and H. B. Robinson Unit 2. The specific objectives of the program were to (1) provide a best estimate of the frequency of a through-the-wall crack in the pressure vessel at each of the three plants, together with the uncertainty in the estimated frequency and its sensitivity to the variables used in the evaluation; (2)

determine the dominant overcooling sequences contributing to the estimated frequency and the associated failures in the plant systems or in operator actions; and (3) evaluate the effectiveness of potential corrective measures. For the Calvert Cliffs Unit 1 study, thousands of hypothetical overcooling events were constructed using computer-generated event trees and quantified branch points. A screening frequency of 10^{-7} per reactor year was used to screen out those event tree branches (scenarios) which had a very low probability of occurring. All remaining scenarios were considered explicitly, and those scenarios screened out were grouped into 11 "residual" groups to ensure that their contributions to the through-the-wall crack frequency were included in the study. Thermal-hydraulics analyses were performed on a few of the scenarios by Los Alamos National Laboratory and the results were reviewed by Brookhaven National Laboratory. In addition, mixing calculations were performed at Purdue University for some of the scenarios. The thermal-hydraulics consequences of all remaining scenarios were estimated by Science Applications International Corporation. For all scenarios, probabilistic fracture-mechanics calculations were performed by ORNL. The results of all these analyses were then integrated by ORNL to predict the frequency of a through-the-wall crack for the plant due to pressurized thermal shock. The best estimate for Calvert Cliffs Unit 1 was determined to be $\sim 7 \times 10^{-8}$ per reactor year at 32 effective full power years. An uncertainty analysis indicated that a factor of about 100 is an appropriate 95% confidence interval, assuming a log-normal uncertainty distribution. Small-break loss-of-coolant accidents occurring under low decay-heat conditions were found to be the most significant contributors to the PTS risk, and the uncertainty in the flaw density in the pressure vessel was found to be the most important contributor to the overall uncertainty in the risk. The most important operator action for negating pressurized thermal shock at Calvert Cliffs Unit 1 is controlling repressurization after a rapid cooldown. This

study considered some system interactions but no external events such as fires, floods, or seismic events.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations, Office of Nuclear Regulatory Research.

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3.63

PRESSURIZED THERMAL SHOCK EVALUATION OF THE H. B. ROBINSON UNIT 2 NUCLEAR POWER PLANT

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[Abstract of ORNL/TM-9567/V1 (NUREG/CR-4183, Vol. 1), and ORNL/TM-9567/V2 (NUREG/CR-4183, Vol. 2) September 1985]

An evaluation of the risk to the H. B. Robinson Unit 2 nuclear power plant (HBR-2) due to pressurized thermal shock (PTS) has been completed by Oak Ridge National Laboratory (ORNL) with the assistance of several other organizations. This evaluation was part of a Nuclear Regulatory Commission program designed to study the PTS risk to three nuclear plants, the other two plants being Oconee Unit 1 and Calvert Cliffs Unit 1. The specific objectives of the program were to (1) provide a best estimate of the frequency of a through-the-wall crack (TWC) in the pressure vessel at each of the three plants, together with the uncertainty in the estimated frequency and its sensitivity to the vari-

ables used in the evaluation; (2) determine the dominant overcooling sequences contributing to the estimated frequency and the associated failures in the plant systems or in operator actions; and (3) evaluate the effectiveness of potential corrective measures. In the study for HBR-2, thousands of hypothetical overcooling events were constructed and quantified using computer-generated event trees and quantified branch points. All scenarios with a frequency greater than 10^{-7} per reactor year were considered explicitly, and those having lower frequencies were assigned to 12 "residual" groups to ensure that their contributions to the TWC frequency were included in the study. Idaho National Engineering Laboratory (INEL) performed thermal-hydraulics analyses for all the identified scenarios, using detailed models for a few of them and simpler models for the remaining ones. The INEL models and results were reviewed by Brookhaven National Laboratory, and, in addition, mixing calculations pertinent to some of the scenarios were performed at Purdue University. Probabilistic fracture-mechanics calculations were performed by ORNL to determine the conditional TWC probability for each scenario, and it was found that, except in extreme cases, the probabilities for the HBR-2 vessel were too low to permit an appropriate illustration of the fracture-mechanics analysis method. Therefore, a hypothetical vessel (designated as HBR-HYPO) which had higher concentrations of the contaminants copper and nickel and a higher initial nil-ductility reference temperature was utilized in the fracture-mechanics analysis. The fracture-mechanics results were then integrated with the sequence frequencies to obtain the TWC frequency. The best estimate for the HBR-HYPO vessel was determined to be $\sim 1.3 \times 10^{-8}$ per year at a nil-ductility temperature of 270°F. An uncertainty analysis indicated that a factor of about 1000 is an appropriate 95% confidence interval, assuming a log-normal uncertainty distribution. Steam-line breaks involving the blow-down of more than one steam generator were found to be the most significant contributors to the PTS risk, and the uncertainty in the flaw density in the pressure vessel was found to be the most important contributor to the overall

uncertainty in the risk. The most important operator actions for negating pressurized thermal shock at HBR-2 are the closure of the main steam isolation valves (MSIVs) following a small or medium-sized steam-line break downstream of the MSIVs and the isolation of auxiliary feedwater to low-pressure steam generators following a steam-line break. This study considered some system interactions but no external events such as fires, floods, or seismic events.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations, Office of Nuclear Regulatory Research.

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Reactor Safety

3.64

AN EXAMINATION OF THE BASES FOR PROPOSED INNOVATIONS IN REACTOR SAFETY TECHNOLOGY

D. L. Moses

(Abstract of paper presented at the 14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 27-31, 1986; Proc. NUREG/CP-0082, Vol. 1, p. 401, February 1987)

This paper employs the criteria for evaluations from the Nuclear Power Option Viability Study to examine the bases for proposed innovations in light water reactor safety technology. These bases for innovation fall into four broad categories as follows: (1) virtually exclusive reliance on passive safety features to preclude core damage in all situations, (2) design simplification using some passive safety features to reduce the frequency of core damage to less than about 10^{-6} per reactor year, (3) passive containment to preclude releases from any accident, and (4) designing to limit licensing attention to one or at least a few systems. Of these, only the first two, and perhaps only the second, hold significant promise for providing for the viability of advanced light water reactors.

Research sponsored by U.S. DOE Office of the Assistant Secretary for Nuclear Energy.

3.65

NUCLEAR POWER OPTIONS VIABILITY STUDY VOLUME I, EXECUTIVE SUMMARY

D. L. Moses *et al.*

(Abstract of ORNL/TM-9780/1, September 1986)

Innovative reactor concepts are described and evaluated in accordance with criteria established in the study. The reactors to be studied were selected on the basis of three ground rules: (1) the potential for commercialization between 2000-2010, (2) economic competitiveness with coal, and (3) the degree of passive safety in the design. The concepts, classified by coolants, were light water reactors, liquid metal reactors, and high-temperature reactors, and most were of modular design. Although the information available is not adequate for a definitive evaluation of economic competitiveness, all of the concepts appear to be potentially viable in the time frame selected. Public and institutional acceptance of nuclear power was found to be affected primarily by four issues: (1) operational safety, (2) waste handling and disposal, (3) construction and operating costs, and (4) the adequacy of management and regulatory controls.

Research sponsored by U.S. DOE Office of the Assistant Secretary for Nuclear Energy.

3.66

**NUCLEAR POWER OPTIONS
VIABILITY STUDY
VOLUME III, NUCLEAR
DISCIPLINE TOPICS**

D. L. Moses *et al.*

(Abstract of ORNL/TM-9780/3, September 1986)

Innovative reactor concepts are described and evaluated in accordance with criteria established in the study. The reactors to be studied were chosen on the basis of three ground rules: (1) the potential for commercialization between 2000-2010, (2) economic competitiveness with coal-fired plants, and (3) the degree of passive safety in the design. The concepts, classified by coolants, were light water reactors, liquid metal reactors, and high temperature reactors, and most were of modular design. All the concepts appear to be potentially viable in the time frame selected, but the information available is not adequate for a definitive evaluation of their economic competitiveness. This volume primarily reports in greater detail on several topics from the study. These are construction, economics, regulation, safety and economic risk, nuclear waste transportation and disposal, and market acceptance. Although treated generically, the topics are presented in the context of the reactor concepts of the study.

Research sponsored by U.S. DOE Office of the Assistant Secretary for Nuclear Energy.

3.67

**APPROACHES TO PASSIVE SAFETY
IN ADVANCED THERMAL REACTORS**

D. L. Moses

[Abstract of paper presented at the International American Nuclear Society/European Nuclear Society Topical Meeting on Thermal Reactor Safety, San Diego, CA, February 2-6, 1986; Proc. Vol. 5, p. 12 (1986)]

Since 1980, there has been a proliferation of thermal reactor designs which incorporate passive safety features. The evolution of this trend is briefly traced, and the nature of various passive

safety features is discussed with regard to how they have been incorporated into evolving design concepts. The key aspects of the passive safety features include reduced core power density, enhanced passive heat sinks, inherent assured shutdown mechanisms, elimination/minimization of potential leak paths from the primary coolant system, enhanced robustness of fuel elements and improved coolant chemistry and component materials. An increased reliance on purely passive safety features typically translates into larger reactor structures at reduced power ratings. Proponents of the most innovative concepts seek to offset the increased costs by simplifying licensing requirements and reducing construction time.

Research sponsored by U.S. DOE Civilian Reactor Development Program.

3.68

**A PWR HYBRID COMPUTER
MODEL FOR ASSESSING
THE SAFETY IMPLICATIONS
OF CONTROL SYSTEMS**

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N. E. Clapp* F. C. DiFilippo
J. P. Renier* A. Sozer†**

[Abstract of *Nucl. Eng. and Design* 89, 113 (1985)]

As part of the ORNL study of safety-related aspects of control systems, a hybrid computer model was developed to trace the dynamic impact of single and multiple component failures on the control system and remainder of the plant. Since the thrust of this program is to investigate control system behavior, the controls are modeled in detail to accurately reproduce characteristic response under normal and off-normal transients. The balance of the model, including neutronics, thermohydraulics and component submodels, is developed in sufficient detail to provide a suitable support for the control system.

The model is being used primarily to address mild to moderate transients that can occur at least partially under action of the non-safety control system. Attention initially focused on overfill events that assumed single or multiple failures of feed valves or the generator low and

high level setpoints and trips that regulate the valves. In general, these calculations showed that for single-generator overfeed, water inventory in the affected generator increased to a sufficiently high level to saturate the generator fluid, quench superheat, and inject water into the steam line. Overcooling of the primary side was modest.

Other events studied with the model include: insufficient main feedwater cooling induced by a steam generator high level setpoint failing low,

potentially drying out the generator; secondary side depressurization induced by turbine bypass valves failing open in loop A or in combination with loop B, at low and high power levels; and steam generator tube ruptures in combination with overcooling incidents.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

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†Computing and Telecommunications Division.

‡Engineering Technology Division.

Stochastic Phenomena

3.69

CHANGES IN THE STATISTICS OF SIGNALS BECAUSE OF THE ACTION OF MEASURING DEVICES

F. C. DiFilippo

(Abstract of paper to be presented at the IEEE 1988 International Conference on Acoustics, Speech, and Signal Processing, New York, NY, April 11-14, 1988)

The transformation of a sequence of random events in time (input) into an analogous signal (output) through the action of a measuring device can drastically influence the statistics of the process under observation. If, for example, each event in a Markovian chain produces a time-dependent signal $f(\tau)$ the superposition of the signals from all the events of the sequence will produce an output signal S at time t which will depend on the previous history, i.e., a non-Markovian process. The statistical properties of S will depend on the statistics of the original signal and the action of the measuring device; an interpretation of the statistical descriptors of S requires then the consideration of the action of the measuring device which is done in this paper.

Research sponsored by U.S. DOE Office of Nuclear Safety.

3.70

CORRELATION OF THE SIGNALS FROM DETECTORS IN THE PRESENCE OF A STOCHASTIC NEUTRON FIELD

F. C. DiFilippo

[Abstract of *Nucl. Sci. Eng.* (in press)]

The source of correlation for the signals from detectors in the presence of a stochastic neutron field is analyzed for a variety of circumstances. A general methodology, based on a master equation approach, is compared with the Langevin/Schottky method with the result that there is consistency if we include the detection process in detail. For cases where the detector removes the detected neutron, the only sources of correlation are elementary processes that produce more than one neutron; consequently, the Schottky prescription for the noise equivalent source has to be corrected accordingly. An additional term induced by the finite electronic resolution is also found and added to the noise equivalent source. Because of the relevance of the subject to the theory of the ^{252}Cf source noise method to measure reactivities, we applied the general results to interpret a recently performed experiment with this type of source.

Research sponsored by U.S. DOE Office of Nuclear Safety.

3.71

GENERAL THEORETICAL FOUNDATION OF THE ^{252}Cf SOURCE NOISE METHOD

F. C. D'Elia

[Abstract of *Trans. Am. Nucl. Soc.* 55, 597 (1987)]

The measurement of reactivities by the ^{252}Cf source noise technique in complicated geometries and/or highly subcritical states requires a general and solid theoretical foundation of the method in order to translate the experimental observables into the multiplication constant. Models based on the absolute dominance of the fundamental mode cannot be applied when complications due to the geometry or the loading preclude the ideal positioning of sources and detectors. Spatial effects can have considerable effects on this method as it can be appreciated using a simple two-points reactor model. A derivation of a general interpretation of the ^{252}Cf method is then necessary.

The field of view of detector i , η_i , is defined by the Fourier Transform of the adjoint Boltzmann equation where the detector cross section is the source of importance and it is expanded in terms of the kinetic adjoints eigenfunctions.

The previous considerations together with the analysis of the source of correlated noise can be applied to the calculation of the stochastic descriptors associated with the ^{252}Cf method. These are the Fourier transforms, G_{ij} (i, j refer to detector labels), of the correlation functions between the fluctuating part of the signals coming from detector 1 (a fission chamber with a ^{252}Cf deposit inside) and neutron detectors 2 and 3. The G_{ij} are given then by Lorentzian plus interference terms in frequency with amplitudes that depend on the projections of the detector field of view on the kinetic adjoint eigenfunctions.

The fitting of the measured G_{1i} ($i = 2, 3$) and G_{23} allow the determination of decay constant α_1 and α_2 and the fundamental mode ratio, $R_{FM} = [G_{12}^* G_{13} / G_{11} G_{23}]_{FM}$

Nevertheless it is the ideal ratio R' measured by ideal detectors (i.e., distributed according to

the fundamental mode) the one that can be related with the reactivity.

The sequence to measure the reactivity is the following: A general nonlinear fit of the experimental data produces α_1, α_2 and R_{FM} ; an iterative process produces ρ and R' . The relationship between R_{FM} and R' is the more difficult step in this process. This is because the relationship depends on integrals of the second mode that presently can not be computed in complicated geometries (e.g., two interacting tanks). A judicious election of detector positions (e.g. symmetric positions in symmetric system) could reduce uncertainties associated with the relationship.

The briefly described theoretical development was successfully applied to the analysis of experiments performed with two equal and two different tanks containing solutions of fissile materials. Parameters associated with the first harmonic were estimated with a two-points reactor model. We can conclude then that the theoretical foundation of the ^{252}Cf noise method to measure reactivities was finally established.

Research sponsored by U.S. DOE Office of Nuclear Safety.

3.72

INTERPRETATION OF SPATIAL EFFECTS IN REACTIVITY MEASUREMENTS WITH THE ^{252}Cf SOURCE NOISE METHOD

F. C. D'Elia

[Abstract of *Trans. Am. Nucl. Soc.* 52, 642 (1986)]

The ^{252}Cf method has been used extensively to measure reactivities in a large variety of situations ranging from a fast reactor mock-up to thermal homogeneous systems. The method is now being applied to arrays of cans (containing fissile solutions) and pieces of uranium metal. The geometrical complications of these kinds of arrangements preclude the use of interpretative models based on a point reactor or on a bare reactor eigenfunction expansion approach. The original limitations of both approaches can be overcome if we develop models based, respectively, on a phenomenological multipoint reactor

formalism or on a postulated eigenfunction expansion. This paper describes the calculation of stochastic observables with a lumped two-point and a continuous two-mode reactor model.

The equations take a particularly simple form in the case of two equal interacting media (like two equal cans containing the same fissile solutions) described with a lumped two-point reactor equation. The rather formal continuous model provides factors to adjust the lumped models that are related to the spatial distribution of source and fission neutrons. The lumped model has the simplifying advantage of allowing stochastic simulations in terms of only six parameters: the multiplication (k) and mean life (l) of neutrons in one can, the coupling constant (k_{12}), the source parameter (ϵ : ratio of first to fundamental mode amplitudes), and the detector parameters (x_2 and x_3 : ratios of the first to fundamental mode amplitudes of the detector's field of view). These simulations reproduce very well the main features of experimental data, demonstrating the suitability of the presented model to interpret ^{252}Cf source noise reactivity measurements in complicated geometries.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

3.73

SOURCE OF CORRELATED NOISE IN EXPERIMENTS USING A ^{252}Cf SOURCE

F. C. D'Alipho

[Abstract of *Trans. Am. Nucl. Soc.* 54, 349 (1987)]

The ^{252}Cf source method to measure reactivities is under intensive study, both theoretically and experimentally, at the Oak Ridge National Laboratory. Potential applications to the measurement of very large subcriticalities ($k_{\text{eff}} \leq 0.5$) require a careful analysis of the source of correlated noise. Still, ^{252}Cf experiments are analyzed by applying the Schottky prescription of the source noise according to Cohn, i.e., without corrections due to the neutrons removed by the detector; this is equivalent to assuming that

detector fluctuations are exactly proportional to the fluctuation of the neutron field. If this is true, a nonzero correlation should be measured in a moderator driven by a one-neutron-per-event source (like a photoneutron source), which certainly is not the case. Sheff and Albrecht emphasized later that the Schottky source of noise has to be divided into two components related to multiple neutrons per event (fission) and to a single neutron per event (absorption plus leakage), and that only the first component is the source of correlated noise for the detector. The differences between the two formalisms have very practical implications when the ^{252}Cf method is applied to measure large subcriticalities. In this paper we analyze systems without multiplication in order to emphasize the differences; also additional sources of correlations due to finite resolution time are individualized and quantified. Whenever possible, we use a master equation approach to avoid *a posteriori* cosmetic to the Langevin/Schottky approach.

The first case, the simplest one, consists of an arrangement where the ^{252}Cf source is inside a fission chamber (detector 1) and two fast neutron detectors (detectors 2 and 3) form an angle θ with the source.

The second case corresponds to the calculation of the autocorrelation function of the response of a detector in a moderator characterized by a decay constant α and excited with a source of intensity S and multiplicity ν at random.

The third case corresponds to the calculation of the APSD of a detector in a moderator where it removes the detector neutrons; it is supposed also that the electronic has a finite resolution time Δ . In this case it is necessary to solve a master equation that includes multiple events during Δ (i.e., more than one absorption or source disintegrations). Under these circumstances, an additional term, proportional to $S\Delta$, appears due to accidental coincidences during resolution time Δ .

The literature, the previous theoretical analysis, and the experimental evidence strongly support that the use of the Schottky prescription of the source of noise in a Langevin modeling of stochastic processes must be corrected to include the

removal of the detected neutrons. Of course, a formalism based on a master equation approach does not require any cosmetic but the Langevin/Schottky approach is sometimes the only possible one. Consequently, only events that produce more than one neutron are the source of correlated noise. In summary, in the same way that we need two persons to dance a tango, we need two neutrons to have a positive correlation in the detection system.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

3.74

NOISE ANALYSIS OF INTERACTIVE FISSILE SYSTEMS USING THE ^{252}Cf NEUTRON SOURCE

F. C. D'Filippo C. March-Lesba

(Abstract of paper presented at the 9th International Conference on Noise in Physical Systems, Montreal (Quebec), Canada, May 25-29, 1987)

The ^{252}Cf neutron source is now being applied to measure the multiplication constants, k_{eff} , and related kinetic parameters of arrays of interacting tanks (containing fissile solutions) and pieces of uranium metals. In this paper we analyze experimental results involving two equal tanks with a lumped two-point coupled-reactor model.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

3.75

INTERPRETATION OF SUBCRITICALITY MEASUREMENTS WITH STRONG SPATIAL EFFECTS

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F. C. D'Filippo

[Abstract of *Trans. Am. Nucl. Soc.* 54, 348 (1987)]

This paper presents a technique to identify and isolate modal or spatial effects in frequency-domain quantities used for subcritical reactivity measurements using the ^{252}Cf -source-driven noise analysis technique. The ^{252}Cf technique is based on measurements of the

system's response to a stochastic californium neutron source with three detectors. Detector 1 measures the source fissions, while 2 and 3 measure the system's response at different locations. Using point kinetics theory, the reactivity can be shown [Eq. (1)] to be almost proportional to the frequency-independent ratio $R = G_{12}^*G_{13}/G_{11}G_{23}$ where G_{ij} is the cross power spectral density (CPSD) between detectors i and j . For certain source-detector configurations, the point kinetics theory is quite valid; however, for other configurations, spatial effects (i.e., modal contaminations) are important and special interpretations are necessary. In the past, two approaches have been successfully utilized: the computation of modal correction factors based on parallel neutron calculations, or functional fits to a two-point kinetics model. Here, we present a different methodology that does not rely on extra neutronic calculations.

The approach taken in this work is to functionally fit the measured CPSDs using a model that accounts for the modal contamination. The fundamental-mode component of the measured quantities is extracted from the fit, and a fundamental-mode ratio is computed. All the current theories can be applied to this ratio. Subcritical reactivities can, in this way, be estimated using the existing proven theories even in cases where the geometry or the high subcriticality would invalidate the point kinetics approximation.

Research sponsored by U.S. DOE Office of Environmental Research and Development.

*Instrumentation and Controls Division.

3.76

A FORMALISM FOR THE STUDY OF STOCHASTIC EIGENVALUE PROBLEMS

R. B. Perez F. C. D'Filippo
G. de Sansaure

(Abstract of paper presented at the 9th International Conference on Noise in Physical Systems, Montreal (Quebec), Canada, May 25-29, 1987)

Many physical systems are described in terms of time-independent stochastic operators, such as

Bohr's statistical model of nuclear reactions and neutron reacting systems where a degree of randomness appears in the spatial distribution of materials. Because of the action of stochastic "potentials," the unperturbed, deterministic eigenvalues and eigenfunctions become random functions whose probability laws can be determined

by either analytical or Monte Carlo simulation techniques. The purpose of this paper is to develop a formalism for the explicit calculation of the eigenset associated with spatially random operators.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

Mathematical Modeling for Military Applications

3.77

COMBAT MODELING WITH PARTIAL DIFFERENTIAL EQUATIONS

V. Protopopescu

(Abstract of invited talk presented at the Applied and Computational Mathematics Program Annual Meeting, Washington, DC, October 5-8, 1987)

An extension of the classical modeling of combat via Lanchester equations to include spatial effects is described. The proposed model, based on nonlinear partial differential equations, together with preliminary numerical results are presented. Possible applications and extensions are reviewed.

Research sponsored by U.S. DOE and Joint Chiefs of Staff.

3.78

COMBAT MODELING WITH PARTIAL DIFFERENTIAL EQUATIONS

V. Protopopescu R. T. Santoro
J. Dockery*

[Abstract of *European J. of Oper. Res.* (in press)]

We propose an extension of the classical modeling of combat via Lanchester equations to include spatial effects. The usual coupled set of ordinary differential (Lanchester) equations is replaced by a system of nonlinear partial differential equations. We discuss the proposed model, report preliminary numerical results, and consider possible applications and extensions.

Research sponsored by U.S. DOD Organization of the Joint Chiefs of Staff, Command, Control, and Communications.

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Mathematical Methods for Nonlinear Systems

3.79

DETERMINISTIC SENSITIVITY THEORY FOR NONLINEAR SYSTEMS: THE FORWARD AND THE ADJOINT METHODS

D. G. Cacuci

[Abstract of ORNL/TM-10058, August 1986; also Book Chapter entitled *The Forward and the Adjoint Methods of Sensitivity Analysis*, Edited by Y. Ronen, Ben Gurion University, CRC Press, Inc. (in press); also Lecture Notes for the ISPRA Course on Data Uncertainties, Sensitivities, Consistencies, and Adjustment, Ispra, Italy, April 7-11, 1986]

Concepts of nonlinear functional analysis are employed to investigate the mathematical founda-

tions underlying sensitivity theory. This makes it possible not only to ascertain the limitations inherent in existing analytical approaches to sensitivity analysis, but also to rigorously formulate a considerably more general sensitivity theory for physical problems characterized by systems of nonlinear equations and by nonlinear functionals as responses. Two alternative formalisms, the Forward Method and the Adjoint Method, are developed in order to evaluate the sensitivity of the response to variations in the system parameters. The forward method is formulated in normed linear spaces, and the existence of the Gateaux differentials of the operators appearing in the problem is shown to be both necessary and

sufficient for its validity. This method is conceptually straightforward and can be advantageously used to assess the effects of relatively few parameter alterations on many responses. On the other hand, for problems involving many parameter alterations or a large data base and comparatively few functional-type responses, the alternative adjoint method is computationally more economical. However, it is shown that this method can be developed only under conditions that are more restrictive than those underlying the validity of the forward method. In particular, the requirement that operators acting on the state vector and on the system parameters must admit densely defined Gateaux derivatives is shown to be of fundamental importance for the validity of this formalism. The present analysis significantly extends the scope of sensitivity theory and provides a basis for still further generalizations.

There are physical systems where a critical point of a function that depends on the system's state vector and parameters defines the location in phase-space where the response functional is evaluated. The Gateaux differentials giving the sensitivities of both the functional and the critical point to changes in the system's parameters are obtained by alternative formalisms. The forward method is the simpler and more general, but may be prohibitively expensive for problems with large data bases. The adjoint method, although less generally applicable and requiring several adjoint calculations, is likely to be the only practical approach. Sensitivity theory is also extended to include treatment of general operators, acting on the system's state vector and parameters, as response. In this case, the forward method is the same as for functional responses, but the adjoint method is considerably different. The adjoint method requires expanding the indirect effect term, an element of a Hilbert space, in terms of elements of an orthonormal basis. Since as many calculations or adjoint functions are required as there are nonzero terms in this expansion, careful consideration of truncating the expansion is needed to assess the advantages of the adjoint method over the forward method.

The sensitivity theory for nonlinear systems with responses defined at critical points of a func-

tion of the system's state variables and parameters is applied to a protected transient with scram on high-power level in the Fast Flux Test Facility. The single-phase segment of the fast reactor safety code MELT-IIIB is used to model this transient. The response analyzed is the maximum fuel temperature in the hot channel. For the purposes of sensitivity analysis, a complete characterization of this response requires consideration of both the numerical value of the response at the maximum, and the location in phase space where the maximum occurs. This is because variations in the system parameters alter not only the value at this maximum but also alter the location of the maximum in phase space.

Expressions for the sensitivities of the numerical value of this maximum-type response and expressions for the sensitivities of the phase-space location at which the maximum occurs are derived in terms of adjoint functions. The adjoint systems satisfied by each of these adjoint functions are derived and solved. It is shown that the complete sensitivity analysis requires (a) the computation of as many adjoint functions as there are nonzero components of the maximum in phase space, and (b) the computation of one additional adjoint function for evaluating the sensitivities of the numerical value of the response. The same computer code can be used to calculate all the required adjoint functions; once these adjoint functions are available, the sensitivities to *all* possible variations in the system parameters are obtained by quadratures. The sensitivities obtained by this efficient method are used to predict both changes in the numerical values of the maximum fuel temperature and the new phase-space location at which the perturbed maximum occurs when the system parameters are varied. These predictions are shown to agree well with direct recalculations using perturbed parameter values.

Finally, we present an efficient method for calculating the sensitivity of a mathematical model's result to feedback. Feedback is defined in terms of an operator acting on the model's dependent variables. The sensitivity to feedback is defined as a functional derivative, and a method is presented to evaluate this derivative

using adjoint functions. Typically, this method allows the individual effect to many different feedbacks to be estimated with a total additional computing time comparable to only one recalculation. It is anticipated that this method of estimating the effect of feedback will be useful for more complex models where extensive recalculations for each of a variety of different feedbacks is impractical.

Research sponsored by U.S. DOE Office of Energy Research.

3.80

LIMIT CYCLES AND BIFURCATIONS IN NUCLEAR SYSTEMS

D. G. Cacuci R. B. Perez
J. March-Leuba*

[Abstract of *Trans. Am. Nucl. Soc.* 53, 239 (1986)]

Recent stability tests have shown that boiling water reactors (BWRs) are susceptible to reactivity instabilities when operated at low-flow conditions. When such instabilities occur, limit cycles are observed in the measured process signals, indicating that these instabilities cause a transition between a linear regime (normal operation) and a nonlinear regime (unstable operation in the linear sense). The purpose of this paper is to describe the phenomenological dynamical behavior of BWRs in the nonlinear regime under deterministic and stochastic excitations. This work provides a basis for scoping calculations to determine the dynamic behavior — both linear and nonlinear — of BWRs. Additional work is now under way to establish the feasibility of routine operation of nuclear systems in the nonlinear (limit-cycle) regime.

Research sponsored by U.S. Department of Energy.

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3.81

DUALS AND PROPAGATORS: A CANONICAL FORMALISM FOR NONLINEAR EQUATIONS

D. G. Cacuci R. B. Perez
V. Protopopescu

[Abstract of *J. Math. Phys.* (in press)]

We propose a new formalism for solving general nonlinear equations. Given a nonlinear operator equation, we construct, canonically, a *dual* operator, similar to the adjoint operator in linear theory. By using this dual operator, we generate advanced and retarded propagators (analogs of the Green's functions in linear theory) that satisfy the customary reciprocity and semi-group properties, and we obtain the formal solution of the nonlinear problem in terms of these propagators. We further show that these propagators can be obtained either by solving a linear equation that still contains an implicit dependence on the problem's solution or by solving a closed-form nonlinear integral equation from which the problem's solution itself is completely eliminated. The entire formalism is canonical in the sense that the particularities of the nonlinear operator, boundary conditions, and the phase space are not relevant to the formalism *per se*. We conclude with an application for which all the aspects of the formalism can be carried through analytically, and discuss other possible applications.

Research sponsored by U.S. Department of Energy.

3.82

EXTENDING GREEN'S FUNCTION FORMALISM TO GENERAL NONLINEAR EQUATIONS

D. G. Cacuci R. B. Perez
V. Protopenescu

[Abstract of paper in the Proceedings for the IVth International Workshop on Nonlinear Evolution Equations and Dynamical Systems, Balaruc-les-Bains, June 11-25, 1987 (in press)]

Forward and backward propagators are canonically obtained for general nonlinear problems and shown to be the natural generalizations of the Green's functions used to solve linear problems. The propagators obey a reciprocity relationship and satisfy a closed nonlinear integral equation. The formalism is applied on an illustrative example.

Research partially sponsored by U.S. Department of Energy and U.S. Department of Defense.

3.83

PROPAGATORS FOR GENERAL NONLINEAR EQUATIONS

D. G. Cacuci R. B. Perez
V. Protopenescu

(Abstract of ORNL/TM-10016, May 1986)

We introduce propagators — advanced and retarded — for nonlinear problems and show that they generalize the Green's functions used to solve linear problems. These propagators are generated by using the *dual* operator which plays, for the nonlinear problem, the same role as the customary adjoint operator for linear problems. The propagators obey a reciprocity relationship and satisfy a closed nonlinear integral equation or, alternatively, a linear integral equation that depends parametrically on the problem's solution. These equations are formulated in a canonical way, independent of dimensionality, boundary conditions and type of the underlying nonlinear problem.

Research sponsored by U.S. DOE Office of Energy Research.

3.84

ON THE EXCITATION OF NEUTRON FLUX WAVES IN REACTOR CORE TRANSIENTS

F. C. Difilippo R. B. Perez

[Abstract of *Nucl. Sci. Eng.* 94, 66 (1986)]

The time response of a critical reactor to a perturbation in the cross sections has been analyzed in terms of the Green's function of the system. In this way it is possible to visualize the perturbation as a source of neutron waves that are reflected at the boundaries of the system. The original and reflected waves could, in principle, interfere with each other in producing resonances in response to the system; nevertheless, the damping of the neutron waves is usually so large that no dominant frequencies appear. Any observed resonant behavior of the neutron flux has then to be produced by a resonance in the perturbation.

Research sponsored by U.S. DOE Office of Energy Research, Division of Nuclear Facility Safety.

3.85

OPTIMAL CONTROL OF NONLINEAR NUCLEAR REACTORS

C. March-Lomba R. B. Perez

[Abstract of *Trans. Am. Nucl. Soc.* 55, 617 (1987)]

This paper presents a new formulation of a class of nonlinear optimal control problems as a solution of a system of differential equations with initial conditions. An application to the control of a nonlinear nuclear reactor is shown.

Pontryagin's theorem has been successfully applied to the problem of designing control systems that are optimum in the sense that they minimize a given cost function. Rosztoczy *et al.* showed how the "maximum principle" can be used to optimize control-rod movement during transients in a nonlinear nuclear reactor by using a point kinetics reactor model with temperature feedback proportional to the flux. The problem

was formulated in a way that demanded the solution of four coupled first-order nonlinear differential equations with initial conditions for the flux and final conditions for the adjoint. This particular set of boundary conditions required an iterative numerical solution of the equations that did not apply easily to real-time applications.

This paper presents a new formulation of the problem that allows on-line solution for the control by transforming it to an initial value problem.

In summary, optimal control techniques can be applied to nuclear reactors. Control constraints, nonlinearities and multivariate control problems can be handled by using variational techniques. The results presented in this paper show that depending on the formulation of the cost function, the solution of the system of equations can be clearly simplified.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

3.86

OPTIMAL PARAMETER TRACKING AND CONTROL OF NONLINEAR SYSTEMS WITH TIME-VARYING PARAMETERS

C. March-Lomba R. B. Perez

(Abstract of paper to be presented at the IEEE 1988 International Conference on Acoustics, Speech, and Signal Processing, New York, NY, April 11-14, 1988)

This paper presents a new formulation of a class of nonlinear optimal control problems in which the system's parameters are changing arbitrarily with time. A variational technique based on Pontryagin's Maximum Principle is used to track the time-varying parameters of the system and to calculate the optimal control. The present formulation allows on-line solutions for parameters and optimal control calculations by re-casting it into the form of an initial value problem. An application to a nonlinear nuclear reactor in which feedback coefficients and detectors time constants are varying is presented.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

Risk, Reliability, and Human Factors

3.87

TOP-DOWN VERSUS BOTTOM-UP PROCESSING OF INFLUENCE DIAGRAMS IN PROBABILISTIC ANALYSIS

R. D. Timmerman* T. J. Burns
H. L. Dodds, Jr.*

[Abstract of *Trans. Am. Nucl. Soc.* 52, 514 (1986)]

Recent work at national laboratories in the U.S. and Britain has shown that influence diagram methodology can be a useful analytical tool in reactor safety studies. An influence diagram is a graphical representation of probabilistic dependence within a system or event sequence. Bayesian statistics are employed to transform the relationships depicted in the influ-

ence diagram into the correct expression for a desired marginal probability (e.g. the top node). Top-down and bottom-up algorithms have emerged as the dominant methods for quantifying influence diagrams. The purpose of this paper is to demonstrate a potential error in employing the bottom-up algorithm when dealing with interdependencies. It will be shown that the absolute error between the two methods varies between 0.0 and 0.25. Conditions for greatest error are discussed.

Research sponsored by U.S. Department of Energy.

*University of Tennessee, Knoxville, TN.

3.88

DEVELOPMENT OF BWR AND PWR EVENT DESCRIPTIONS FOR NUCLEAR FACILITY SIMULATOR TRAINING

R. J. Carter C. R. Bovell*

(Abstract of paper presented at the Seventh Symposium on the Training of Nuclear Facility Personnel, Orlando, FL, April 27-30, 1987)

A number of tools that can aid nuclear facility training developers in designing realistic simulator scenarios have been developed. This paper describes each of the tools, i.e., event lists, events-by-competencies matrices, and event descriptions, and illustrates how the tools can be used to construct scenarios.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Human Factors Technology.

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3.89

TAPS — AN AUTOMATED TOOL FOR IDENTIFICATION OF SKILLS, KNOWLEDGES, AND ABILITIES USING NATURAL LANGUAGE TASK DESCRIPTION

C. C. Jorgensen R. J. Carter

[Abstract of paper presented at the ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville, TN, April 21-24, 1986; Proc. p. 202 (1986)]

A prototype, computer-based tool (TAPS) has been developed to aid training system developers in identifying skills, knowledges, and abilities (SKAs) during task analysis. TAPS uses concepts of flexible pattern matching to evaluate English descriptions of job behaviors and to recode them as SKA lists. This paper addresses the rationale for TAPS and describes its design including SKA definitions and task analysis logic. It also presents examples of TAPS's application.

Research sponsored by U.S. Nuclear Regulatory Commission.

3.90

NUCLEAR POWER PLANT SIMULATION FACILITY EVALUATION METHODOLOGY: HANDBOOK

K. R. Laughery, Jr.* R. J. Carter
P. M. Haas

[Abstract of ORNL/TM-9570/V1 (NUREG/CR-4188, Vol. 1), January 1986]

This report is Volume 1 of a two-part document which describes a research and development project conducted for the Nuclear Regulatory Commission (NRC). The purpose of the effort was to develop a methodology to evaluate the acceptability of nuclear power plant (NPP) simulation facilities for use in the simulator-based portion of NRC's operator licensing examination.

The proposed methodology is to be utilized during two phases of the simulation facility life-cycle, initial simulator acceptance and recurrent analysis. Initial evaluation is to be performed when a simulation facility is acquired, in the case of new simulators, and as soon as is practical for existing simulators. The first phase is aimed at ensuring that the simulation facility provides an accurate representation of the reference NPP. There are two components of initial simulator evaluation: fidelity assessment and a direct determination of the simulator's adequacy for operator testing (i.e., evaluation of operator/trainee performance). Recurrent evaluation is aimed at ensuring that the simulation facility continues to accurately represent the reference plant throughout the life of the simulator. This phase involves three components: monitoring reference plant changes, monitoring the simulator's hardware, and examining the data from actual plant transients as they occur.

Volume 1 is a set of guidelines/procedures to be followed by individuals involved in the simulation facility evaluation process. It details the steps involved in the two life-cycle phases. The handbook also presents an overview of the methodology and data collection requirements, and addresses the formation of the evaluation team

and the preparation of the evaluation plan. Volume 2 describes the technical bases and the development of the methodology.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations.

*Micro Analysis and Design, Boulder, CO.

3.91

NUCLEAR POWER PLANT SIMULATION FACILITY EVALUATION METHODOLOGY: TECHNICAL BASES

**K. R. Laughery, Jr.* R. J. Carter
P. M. Haas**

[Abstract of ORNL/TM-9570/V2 (NUREG/CR-4188, Vol. 2), January 1986]

This report is Volume 2 of a two-part document which describes a research and development project conducted for the Nuclear Regulatory Commission (NRC). The purpose of the effort was to develop a methodology to evaluate the accountability of nuclear power plant (NPP) simulation facilities for use in the simulator-based portion of NRC's operator licensing examination.

The proposed methodology is to be utilized during two phases of the simulation facility life-cycle, initial simulator acceptance and recurrent analysis. Initial evaluation is to be performed when a simulation facility is acquired, in the case of new simulators, and as soon as is practical for existing simulators. The first phase is aimed at ensuring that the simulation facility provides an accurate representation of the reference NPP. There are two components of initial simulator evaluation: fidelity assessment and a direct determination of the simulator's adequacy for operator testing (i.e., evaluation of operator/trainee performance). Recurrent evaluation is aimed at ensuring that the simulation facility continues to accurately represent the reference plant throughout the life of the simulator. This phase involves

three components: monitoring reference plant changes, monitoring the simulator's hardware, and examining the data from actual plant transients as they occur.

Volume 2 describes the development of and technical bases for the evaluation methodology, including a discussion of the major issues, research base, and judgements/decisions made by the research team. Volume 1 is a set of guidelines/procedures to be used by individuals involved in the simulation facility evaluation process.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations.

*Micro Analysis and Design, Boulder, CO.

3.92

INTEGRATED OPERATOR-PLANT PROCESS MODELING AND DECISION SUPPORT FOR ALLOCATION OF FUNCTION

J. C. Schryver H. E. Kneec

(Abstract of paper to be presented at the Human Factors Society 31st Annual Meeting, New York, NY, October 19-23, 1987)

Human operator simulation models can play an important information role in the allocation of functions in person-machine systems. A prototype simulation model system developed at ORNL is described in which a human operator model (INTEROPS) and a nuclear power plant (NPP) process model are dynamically integrated. INTEROPS is a cognitive/performance simulation model which is itself a dynamic integration of a SAINT task network model and a knowledge-based subsystem which reasons with uncertainty. Potential contributions of INTEROPS to NPP advanced control design are evaluated.

Research sponsored by U.S. DOE Office of Technology Support Programs.

3.93

KNOWLEDGE-ENHANCED NETWORK SIMULATION MODELING OF THE NUCLEAR POWER PLANT OPERATOR

J. C. Schryver L. E. Palko*

(Abstract of paper to be presented at the Society for Computer Simulation 1988 Multiconference, San Diego, CA, February 3-5, 1988)

Simulation models of the human operator of advanced control systems must provide an adequate account of the cognitive processes required to control these systems. The Integrated Reactor Operator/System (INTEROPS) prototype model was developed at Oak Ridge National Laboratory (ORNL) to demonstrate the feasibility of dynamically integrating a cognitive operator model and a continuous plant process model (ARIES-P) to provide predictions of the total response of a nuclear power plant during upset/emergency conditions. The model consists of a SAINT network of cognitive tasks enhanced with expertise provided by a knowledge-based fault diagnosis model. The INTEROPS prototype has been implemented in both closed and open loop modes. The prototype model is shown to be cognitively relevant by accounting for cognitive tunneling, confirmation bias, evidence chunking, intentional error, and forgetting.

Research sponsored by U.S. DOE Office of Technology Support Programs.

*University of Tennessee, Knoxville, TN.

3.94

MAINTENANCE PERSONNEL PERFORMANCE SIMULATION (MAPPS) MODEL: FIELD EVALUATION/VALIDATION

A. I. Siegel* J. J. Wolf*
W. D. Bartter* E. G. Madden*
F. F. Kopstein*

[Abstract of ORNL/TM-9503 (NUREG/CR-4104), August 1985]

This report discusses the results of efforts focused upon the evaluation of the practicality,

acceptability, usefulness and validity of the *MA*intenance *P*ersonnel *P*erformance Simulation (MAPPS) model. Subsequent to the completion of model development efforts, MAPPS was subjected to a number of evaluations that included table-top analyses, case study analyses, analyses involving the correlation of MAPPS output to the consensus of subject matter experts, and analyses involving the correlation of MAPPS output to directly observed empirical data gathered in the field. Results of these evaluation efforts are reported in this report. Overall results indicate that no unduly burdensome practicality issues were identified. In addition, identified user groups (the U.S. Nuclear Regulatory Commission, nuclear power plant maintenance supervisors, and architect and engineering firms) rated the model as having relatively high acceptability and found the model to be very useful for a number of specific problems relating to user group interests. Predictive validity was also shown to be in good agreement with both the consensus of subject matter experts and with the empirical data observed in the field. The positive results of the accomplished evaluation efforts indicate that the model is ready for widespread application.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*Applied Technical Associates, Inc., Paoli, PA.

3.95

MAINTENANCE PERSONNEL PERFORMANCE SIMULATION (MAPPS) MODEL: USERS' MANUAL

F. F. Kopstein* J. J. Wolf*

[Abstract of ORNL/TM-9545 (NUREG/CR-3634), September 1985]

This document serves as the users' manual for the *MA*intenance *P*ersonnel *P*erformance Simulation (MAPPS) model. MAPPS is a generalized, stochastic computer simulation model which simulates the performance of maintenance personnel in nuclear power plants. The model considers workplace, maintenance technician,

motivational, human factors, and task-oriented variables to yield predictive information about the effects of these variables on successful maintenance task performance. As such, MAPPS is believed to represent a fundamental probabilistic risk assessment (PRA) analytic tool. Moreover, it serves the needs of nuclear power plant maintenance management for maintenance operations analysis, and the needs of architectural and engineering firms for maintenance system design evaluation. This manual deals only with the procedural aspects of operating the MAPPS computer program. A complete description of the content and logic of the MAPPS model is contained in the two-volume NUREG/CR-3626.

The first section of the present report describes the use of the MAPPS model within the nuclear power plant context. This section also presents the principal potential uses of the model and the major types of information that can be helpful to its various types of users in making decisions. Section 2.0 provides an overview of MAPPS utilization and explains the process of planning and executing simulation runs. Data input requirements are outlined, and the various data types are explained. Also, the model's data outputs are illustrated. Section 3.0 provides the detailed guidance to users for interacting with MAPPS via a terminal. It explains the procedures for controlling all aspects of a simulation.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*Applied Technical Associates, Paoli, PA.

3.96

AN ADVANCED NUCLEAR REACTOR RELIABILITY, AVAILABILITY, AND MAINTAINABILITY DATA BANK AND DATA ANALYSIS CENTER

H. E. Klee

[Abstract of book chapter, Elsevier Applied Science Publishers Ltd., United Kingdom, Gil Cannon, Ed. (in press)]

The Centralized Reliability Data Organization (CREDO) is a data bank and data analysis center, which since 1985 has been jointly sponsored by the United States Department of

Energy's (U.S. DOE's) Office of Technology Support Programs, and Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC). It focuses on reliability, availability, and maintainability (RAM) data that pertain to components (e.g., valves, pumps, etc.) operating in advanced nuclear reactor facilities. As originally intended, the purpose of the CREDO system was to provide a centralized source of accurate, up-to-date data and information for use in RAM analyses necessary for meeting DOE's data needs in the areas of advanced reactor safety assessments, design, and licensing. In particular, creation of the CREDO system was considered an essential element needed to fulfill the DOE Breeder Reactor Safety Program's commitment of, "...identifying and exploiting areas in which probabilistic methods can be developed and used in making reactor safety Research and Development (R&D) choices and optimizing designs of safety systems."

Research sponsored by U.S. DOE Office of Technology Support Programs and Japan's Power Reactor and Nuclear Fuel Development Corporation.

3.97

HUMAN FACTORS REVIEW FOR SEVERE ACCIDENT SEQUENCE ANALYSIS

**P. A. Kreis P. M. Haas
J. J. Manning R. Boveil***

[Abstract of ORNL/TM-9266 (NUREG/CR-3887), November 1985]

This report describes a human factors research project performed to: (1) support the Severe Accident Sequence Analysis (SASA) program and (2) develop a descriptive model of operator response in accident management. The first goal was accomplished by working with SASA analysts on the Browns Ferry Unit One anticipated transient without scram (ATWS) accident sequence to systematically assess critical operator actions and thereby demonstrate contributions to SASA analyses from human factors data and methods. The second goal was accomplished by developing a model called the Function

Oriented Accident Management (FOAM) model, which provides both a conceptual structure linking off-normal safety functions with potential unconventional emergency responses and a method for developing technical guidance for those responses based on operations, engineering, and human factors data and expertise. The four components comprising the model are described and their use is shown through a table-top demonstration.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*General Physics Corporation, Chattanooga, TN.

3.98

TSORT — AN AUTOMATED TOOL FOR ALLOCATING TASKS TO TRAINING STRATEGIES

R. J. Carter C. C. Jorgensen

[Abstract of paper presented at the ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville, TN, April 21-24, 1986; Proc. p. 209 (1986)]

An automated tool (TSORT) that can aid training system developers in determining which training strategy should be applied to a particular task and in grouping similar tasks into training categories has been developed. This paper describes the rationale for TSORT's development and addresses its structure, including training categories, task description dimensions, and categorization metrics. It also provides some information on TSORT's application.

Research sponsored by U.S. Nuclear Regulatory Commission.

3.99

AN EXAMINATION OF MAINTENANCE ACTIVITIES IN LIQUID METAL REACTOR FACILITIES: AN ANALYSIS BY THE CENTRALIZED RELIABILITY DATA ORGANIZATION (CREDO)

**M. J. Haire* H. E. Knece
J. J. Manning J. F. Manneschildt*
K. Setoguchi†**

(Abstract of paper presented at the Reliability '87 Conference, Birmingham, England, April 14-16, 1987)

The Centralized Reliability Data Organization (CREDO) is the largest repository of liquid metal reactor (LMR) component reliability data in the world. It is jointly sponsored by the U.S. Department of Energy (DOE) and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. The CREDO database contains information on a population of more than 21,000 components and approximately 1,300 event records. Total experience is approaching 1.2 billion component operating hours. Although data gathering for CREDO concentrates on event (failure) information, the work reported here focuses on the maintenance information contained in CREDO and the development of maintenance critical items lists. That is, components are ranked in prioritized lists from worse to best performers from a maintenance standpoint.

It was found that the restoration of only a very few components contributes to the majority of downtime: The five highest ranked equipment components compose 56% of the total downtime in the Experimental Breeder Reactor (EBR-II), 46% in the Fast Flux Test Facility (FFTF), and 41% in the Experimental Fast Reactor (JOYO). Although the dominate mode of failure differs, mechanical sodium coolant pumps are primary contributors to restoration time for all three reactors.

Long repair in mechanical components are primarily due to the inaccessibility and the awkwardness of dealing with large equipment. The environment in which the equipment is located,

the inability to always detect deteriorating component performance, slow diagnosis of electrical failures, and long retest times are other contributors to low maintainability. Designing for maintenance during early facility design phases would alleviate many problems concerning accessibility and environment. Better non-intrusive surveillance electronics would enable earlier detection, better diagnosis, and faster retest times.

Research sponsored by U.S. DOE Office of Technology Support Programs.

^{*}Fuel Recycle Division.

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[‡]Experimental Reactor Division, O-Arai Engineering Center, Power Reactor and Nuclear Fuel Development Corporation, Oarai, Ibaraki, Japan.

3.100

AN EXAMINATION OF RELIABILITY CRITICAL ITEMS IN LIQUID METAL REACTORS: AN ANALYSIS BY THE CENTRALIZED RELIABILITY DATA ORGANIZATION (CREDO)

B. L. Humphrys^{*} M. J. Haire[†]
K. H. Koger[‡] J. F. Mannesmann[‡]
K. Setoguchi⁺ R. Nakai[†]
Y. Okubo^{**}

(Abstract of a paper presented at the American Nuclear Society International Conference on Fast Breeder Systems: Experience Gained and Path to Economical Power Generation, Kennewick, WA, September 13-17, 1987)

The Centralized RELiability Data Organization (CREDO) is the largest repository of liquid metal reactor (LMR) component reliability data in the world. It is jointly sponsored by the U.S. Department of Energy (DOE) and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. The CREDO data base contains information on a population of more than 21,000 components and approximately 1,300 event records. A conservative estimation is that the total component operating hours is approaching 3.5 billion hours. Because data gathering for CREDO concentrates on event (failure) information, the work reported here focuses on the reliability information contained in CREDO and the

development of reliability critical items lists. That is, components are ranked in prioritized lists from worst to best performers from a reliability standpoint.

Research sponsored by U.S. DOE Office of Technology Support Programs.

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3.101

PLANT RISK STATUS INFORMATION MANAGEMENT SYSTEM

D. J. Campbell^{*} B. C. Ellison^{*}
J. C. Glynn[†] G. F. Flanagan

(Abstract of paper presented at the International Topical Meeting on Computer Applications for Nuclear Power Plant Operation and Control, Richland, WA, September 8-12, 1985)

The Plant Risk Status Information Management System (PRISIMS) is a PC program that presents information about a nuclear power plant's design, its operation, its technical specifications, and the results of the plant's probabilistic risk assessment (PRA) in a logically and easily accessible format. PRISIMS provides its user with unique information for integrating safety concerns into day-to-day operational decisions and/or long-range management planning. PRISIMS was developed for NRC inspection personnel to help them allocate their efforts to actions that have the greatest potential for reducing plant risk. The type of information contained in PRISIMS, the presentation format, and the rapid accessibility make PRISIMS useful for other regulatory personnel and nuclear utility personnel.

Research sponsored by U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research.

^{*}JBF Associates, Inc., Knoxville, TN.

[†]U.S. Nuclear Regulatory Commission, Washington, DC.

3.102

OPERATIONAL PHASE OF INSPECTION PRIORITIZATION

D. J. Campbell* V. H. Guthrie*
G. F. Flanagan

(Abstract of paper presented at the 13th Water Reactor Safety Information Meeting, National Bureau of Standards, Washington, DC, October 1985; Proc. NUREG/CP-0072, October 1985)

Inspectors must make many decisions on the allocation of their efforts. To date, these decisions have been made based upon their own judgment and guidance from inspection procedures. Our goal is to provide PRA information as an additional aid to inspectors. A structured approach for relating PRA information to specific inspector decisions has been developed. The use of PRA information as an aid in optimal decision making (1) in response to the current plant status and (2) in the scheduling of effort over an extended period of time is considered.

Research sponsored by U.S. Nuclear Regulatory Commission, Division of Risk Analysis and Operations.

*JBF Associates, Inc., Knoxville, TN.

3.103

RISK ASSESSMENT APPLICATION TO NRC INSPECTION PROGRESS REPORT FOR THE PERIOD JANUARY 1985 TO JANUARY 1986

D. J. Campbell* V. H. Guthrie*
J. R. Kirchner* H. M. Paula*
B. C. Ellison* F. M. Dycus*
G. F. Flanagan

(Abstract of ORNL-10001 (NUREG/CR-4560), June 1986)

The Risk Assessment Application to the NRC Inspection Program has two objectives: (1) to evaluate the use of probabilistic risk assessment (PRA) results for NRC inspection decision-making purposes, and (2) to supply inspection personnel with PRA results and the results of other safety studies in a format that will help them decide where to focus their efforts to reduce plant risk. We have accomplished the first objec-

tive by identifying decisions inspectors need to make and then determining what PRA-related information can be used to support each decision, and we have partially accomplished the second project objective by developing the PRISIM computer program.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*JBF Associates, Inc., Knoxville, TN.

3.104

NUCLEAR ENERGY, RISK ANALYSIS

G. F. Flanagan

(Abstract of a chapter in the *Encyclopedia of Physical Science and Technology*, Vol. 9, pp. 214-236, Robert Meyers, Editor-in-Chief, Academic Press, Inc., Orlando, FL, 1987)

The risks associated with nuclear energy have been a topic of discussion from the inception of its use for electricity production. This article traces the history of the development of a methodology for assessing nuclear power risk. It contains a rather detailed discussion of the methods and the results of risk analysis to date. It also includes a discussion of the implications and use of risk analysis in regulatory and industry decision making. Finally, in order to put the risk of nuclear power in perspective, nuclear risk is compared with other risks.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

3.105

PRISIM — A COMPUTER PROGRAM THAT MAKES PRA USEFUL

J. B. Fussell* D. J. Campbell*
J. C. Glynn* G. R. Burdick*

(Abstract of paper presented at the IAEA Technical Committee Meeting on Status, Experience, and Future Prospects for the Development of Probabilistic Criteria, Vienna, Austria, January 27-31, 1986)

PRISIM is an IBM personal computer program that translates probabilistic risk assessment (PRA) information and calculates additional PRA type information for use by those who are

not PRA experts. Specifically, PRISIM was developed for the U.S. Nuclear Regulatory Commission for use by their resident inspectors at nuclear power plants. Inspector activities are either scheduled or are in response to a particular status of a plant. PRISIM is useful for either activity.

Research sponsored by U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research.

*JBF Associates, Inc., Knoxville, TN.

†U.S. Nuclear Regulatory Commission, Washington, DC.

3.106

COMPBRN III — A COMPUTER CODE FOR MODELING COMPARTMENT FIRES

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G. Apostolakis* G. F. Flanagan

[Abstract of ORNL/TM-10005 (NUREG/CR-4566), July 1986]

The computer code COMPBRN III deterministically models the behavior of compartment fires. This code is an improvement of the original COMPBRN codes. It employs a different air entrainment model and numerical scheme to estimate properties of the ceiling hot gas layer model. Moreover, COMPBRN III incorporates a number of improvements in shape factor calculations and error checking, which distinguish it from the COMPBRN II code. This report presents the ceiling hot gas layer model employed by COMPBRN III as well as several other modifications. Information necessary to run COMPBRN III, including descriptions of required input and resulting output, are also presented. Simulation of experiments and a sample problem are included to demonstrate the usage of the code.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*University of California, Los Angeles, CA.

3.107

A COMMON CAUSE FAILURE ANALYSIS OF THE RODDED SCRAM SYSTEM OF THE ARKANSAS NUCLEAR ONE-UNIT 1 PLANT

D. F. Montague* D. J. Campbell*
G. F. Flanagan

(Abstract of ORNL/TM-10045, October 1986)

Probabilistic risk assessments (PRAs) of nuclear power plants frequently identify common cause failures (CCFs) as major contributors to plant risk. However, the methods employed to analyze CCFs in PRAs are usually empirical techniques that do not systematically address all CCF scenarios and do not identify specific causes of CCFs.

This study presents the results of using formal common cause failure analysis (CCFA) methods in a detailed reliability analysis of a nuclear power plant safety system. The study identified both important and unimportant general causes of CCFs for a rodded scram system, as well as specific causes within the important general categories. Through this study we established many of the strengths and practical limitations of performing a detailed, systematic CCFA. As a result of this work, we developed a draft set of guidelines for performing a dependent failure analysis. These newly developed guidelines are now being finalized as a set of recommended procedures.

Research sponsored by U.S. Nuclear Regulatory Commission.

*JBF Associates, Knoxville, TN.

Section 4

MACHINE INTELLIGENCE AND MATHEMATICAL MODELING

4.0. INTRODUCTION

C. R. Weisbin

Publications this year are indicative of our research in mechanisms, dynamics, and controls; concurrent computation and neural networks; planning, problem solving, and learning; vision and multisensor integration; world modeling; and man-machine symbiosis. Cooperative research with Fuel Recycle Division, Instrumentation and Controls Division, and Engineering Division is enhanced through our participation in the Robotics and Intelligent Systems Program. Our studies in artificial intelligence (e.g., expert system task planning and supervision, machine learning, vision, multisensor integration) are validated experimentally using the HERMIES robot series. The promise of neural networks and the great potential for human-machine symbiosis receive significant emphasis.

Our modeling and simulation activities still span several domains including energy-economy modeling, nuclear waste isolation, and radiation dosimetry. The common thread binding these distinct disciplines is our approach to automated sensitivity analyses and stress upon quantitative determination of the reliability of results obtained via simulation. Publications this year have emphasized the newly validated capability for automatically determining sensitivities for a wide variety of applications. Research in progress emphasizes a hybrid statistical and deterministic approach to uncertainty analysis, the capability for performing sensitivity calculations in real-time, and methods for decision making under uncertainty.

Mechanisms, Dynamics, and Control

4.1

ADVANCED MANIPULATION FOR AUTONOMOUS MOBILE ROBOTS

S. M. Babcock* W. R. Hamel*
S. M. Killough*

[Abstract of paper presented at the American Nuclear Society International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, WA, March 29 — April 2, 1987; Proc. p. 290 (1987)]

This paper describes the development, mechanical configuration, and control system architecture of a lightweight, high performance, seven-degree-of-freedom manipulator at the Center for Engineering Systems Advanced Research (CESAR). Current activities focusing on modeling and parameter identification will provide a well characterized manipulator for analytical and experimental research in manipulator dynamics and controls, coordinated manipulation, and autonomous mobile robotics.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

4.2

INVERSE DYNAMICS POSITION CONTROL OF A COMPLIANT MANIPULATOR

M. G. Forrest-Barlach* S. M. Babcock*

[Abstract of paper presented at the IEEE 1986 International Conference on Robotics and Automation, San Francisco, CA, April 7-10, 1986; Proc. Vol. 1, p. 196 (1986)]

The cycle time of typical industrial manipulators is limited by vibrational characteristics associated with drive train compliance. In this paper the effects of drive train compliance and actuator dynamics in a two-degree-of-freedom manipulator are modeled and a position controller based on inverse dynamics is developed. For comparison, independent joint control neglecting compliance and independent joint control including actuator dynamics and drive train compliance are also considered. Simulation of various controllers is

performed utilizing the Advanced Continuous Simulation Language. It is shown that the closed loop frequency response of the manipulator can be increased beyond typical industrial practices by considering the drive train compliance in the design and providing suitable feedback measurements. Simulations suggest that satisfactory performance can be obtained as high as the limit imposed by the manipulators unmodeled higher vibration modes. The controller based on inverse dynamics is shown to effectively decouple the manipulator's nonlinearly coupled degrees of freedom and perform better than a linear independent joint controller which also considers drive train compliance.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Wayne State University, Detroit, MI.

†Instrumentation and Controls Division.

4.3

MANIPULATOR TECHNOLOGY: THE CRITICAL ELEMENT OF USEFUL AUTONOMOUS "WORKING" MACHINES

W. R. Hamel* S. M. Babcock*

(Abstract of paper presented at the Intelligent Autonomous Systems Conference, Amsterdam, The Netherlands, December 8-11, 1986)

In this paper, the structure and characteristics of mobile autonomous robots which can perform useful work are discussed. The objective of the discussion is to assess the state of the technology particularly with regard to robot mechanization and the implementation of a "human-like" performance capability. Technology limitations in manipulators and locomotion are significant. If not task constrained, it appears that an anthropomorphic autonomous robot would likely be much larger physically and an order of magnitude heavier than a human equivalent. Research in high performance, lightweight manipulators, servactuators, and power supply systems is needed.

Research sponsored by U.S. Army Human Engineering Laboratory.

*Instrumentation and Controls Division.

Concurrent Computation and Neural Networks

4.4

CONCURRENT ALGORITHMS FOR ASYNCHRONOUS NEURAL NETWORKS

J. Barhen

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

The minimization of the objective function in a combinatorial optimization problem can be carried out using a variety of techniques including nonlinear differential equations, simulated annealing and gradient projection methods. The direct evaluation of this function is in general extremely expensive computationally. Thus, even if a Fast Simulated Annealing (FSA) approach is used, there is a strong incentive to develop algorithms designed from the groundup for easy implementation on concurrent computers.

This paper presents a novel approach toward the optimization of the computational load in message-passing multiprocessor systems. This approach is expected to significantly contribute to the efficient use of hypercube supercomputers onboard mobile robots dedicated to time-critical missions. Our methodology is based on a new optimization model, compact neuromorphic data structures and analytic evaluation of single-neuron perturbation effects on the system's configuration energy. The methodology is implemented via parallel algorithms on an NCUBE hypercube and results for a typical robotic application are discussed in terms of FSA and asynchronous neural networks.

Research sponsored by U.S. DOE Office of Military Applications and the Engineering Research Program.

4.5

SIMULATION OF THE STOCHASTIC DYNAMICS OF NEURAL NETWORKS ON A HYPERCUBE SUPERCOMPUTER

J. Barhen

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

Difficulties in understanding and modeling the cognitive functions of the human brain have long been recognized as a fundamental constraint on progress in the area of machine intelligence. Recent years have witnessed an increased effort in modeling the central nervous system in terms of "neural nets," i.e., distributed stochastic nonlinear dynamical systems. This renewed interest has been aroused by Hopfield's suggestion to use networks of threshold automata for retrieving partially altered or noise-corrupted information.

In this paper we consider learning and associative memorization as a nonlinear dynamic process and model the evolution of asymmetric synaptic connections using a Lyapunov "energy" function. Both long and short term memory effects are simulated in a stochastic framework. A generalized Hopfield model which can process ultrametric patterns is developed, and its simulation is carried out using concurrent algorithms implemented on the NCUBE supercomputer.

Research sponsored by the U.S. Air Force Wright Aeronautical Laboratories.

4.6

COMBINATORIAL OPTIMIZATION OF THE COMPUTATIONAL LOAD BALANCE FOR A HYPERCUBE SUPERCOMPUTER

J. Barhen

[Abstract of paper presented at the Fourth Symposium on Energy Engineering Sciences, Argonne National Laboratory, Argonne, IL, May 7-9, 1986; Proc. DOE/CONF/8605122, p. 71, ANL (May 1986)]

In order to take full advantage of the new generation of VLSI-based concurrent supercomputers, it is essential to develop powerful methods for achieving efficiently system-wide balance of the computational load. We address this combinatorial optimization problem by exploring a variety of approaches, including graph-theoretic algorithms for deterministic scheduling, techniques based on statistical-mechanics analogies such as simulated annealing and cellular automata. This paper summarizes the status of our ongoing effort and gives some preliminary results.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.7

INTELLIGENT OPERATING SYSTEMS FOR BATTLEFIELD ROBOTICS: REAL-TIME PERFORMANCE ON A VLSI HYPERCUBE SUPERCOMPUTER

J. Barhen

[Abstract of paper presented at a Workshop on Automation and Robotics for Military Applications, Huntsville, AL, October 22-23, 1986]

Specialized computer architectures for applications to intelligent autonomous systems at ORNL/CESAR are based on the hypercube ensemble concept. We summarize the status of our algorithm development, carried out in FY 86 under joint DOD/AFWAL and DOE/BES funding, and outline research goals for FY 87, with emphasis on applications such as battle management, threat tracking and weapon allocation.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

4.8

PROGRAMMING ROBOTICS APPLICATIONS ON AN ADVANCED HYPERCUBE MULTIPROCESSOR

J. Barhen

(Abstract of paper presented at the International NATO Workshop on Languages for Sensor-Based Control in Robotics, Castelvécchio Pascoli, Italy, September 1-5, 1986)

Specialized computer architectures for advanced robotics applications at ORNL/CESAR are based on the hypercube ensemble concept. We summarize the current status of algorithm development and present results for robot dynamics and navigation problems.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

4.9

HYPERCUBE ENSEMBLES: AN ARCHITECTURE FOR INTELLIGENT ROBOTS

J. Barhen

[Abstract of Chapter 8 in *Special Computer Architectures for Robotics and Automation*, pp. 195-236, Professor J. Graham, Ed., Gordon and Breach, NY (1987)]

The advent of VLSI technology and its implementation in the design of a new generation of computer systems involving a high degree of concurrency is opening tremendous opportunities for a wide spectrum of applications which require "supercomputing" capabilities. We focus on hypercube ensembles, a revolutionary advance in the expanding domain of concurrent computation machines. Critical issues in the development of algorithms for such message-passing architectures are addressed in the context of intelligent autonomous systems, with emphasis on task scheduling and load balancing. We also present the detailed implementation of the Newton-Euler inverse dynamics equations for a robot manipulator on the NCUBE supersystem.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

4.10

ADVANCES IN CONCURRENT COMPUTATION FOR MACHINE INTELLIGENCE AND ROBOTICS

J. Barhen J. R. Einstein
C. C. Jorgensen

[Abstract of paper presented at the Second International Conference on Supercomputing, Santa Clara, CA, May 3-8, 1987; Proc. Vol. 2, p. 84 (1987)]

New methodologies must be developed for effective use of hypercube multiprocessors to meet the special requirements of Intelligent Robotics concerned with time-critical applications. The aim of this paper is to provide an overview of our initial experiences in this area, focusing on multiprocessor load-balance, mobile robotics and neural network algorithms.

Research sponsored by U.S. DOE Office of Military Applications and Office of Basic Energy Sciences.

4.11

ROSES: AN EFFICIENT SCHEDULER FOR PRECEDENCE — CONSTRAINED TASKS ON CONCURRENT MULTIPROCESSORS

J. Barhen E. C. Halbert*

[Abstract of paper presented at the First Conference on Hypercube Multiprocessors, Knoxville, TN, August 26-27, 1985; Proc. *SIAM Philadelphia* p. 123 (1986)]

One of the first, and perhaps one of the most important steps in attempting to solve a problem on a concurrent computation ensemble is its decomposition into a set of tasks (or processes). Problem decomposition often induces precedence constraints among the tasks, which the distributed nature of the computational system translates into message passing requirements. The efficient scheduling of sets of tasks among which complex interrelationships (such as precedence constraints) may exist is essential for achieving optimal performance from the new generation of concurrent supercomputers. This paper focuses on the ROSES system, which is being developed to schedule precedence-constrained tasks for compu-

tation by an ensemble of concurrent processors. This endeavor is particularly difficult when the number of tasks required exceeds the number of available processors, or when the interconnection topology of the task graph differs from the interconnection topology of the computation ensemble. The ROSES approach seeks near-optimal solutions by combining heuristic techniques to minimize scheduling time as a function of the number and relationship of tasks, with sophisticated data structures to most efficiently utilize available computer memory, and algorithms to control search and eliminate dead ends. The methodology is applied to the solution of the inverse dynamics equations of a robot manipulator and benchmark results are included.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

*University of Tennessee, Knoxville, TN.

4.12

ADVANCES IN CONCURRENT COMPUTERS FOR AUTONOMOUS ROBOTS

J. Barhen E. C. Halbert*
J. R. Einstein

(Abstract of paper presented at the Second World Conference on Robotics Research, Scottsdale, AZ, August 18-21, 1986)

Some of the most challenging computational requirements facing scientists and engineers today arise within the framework of intelligent autonomous systems. To enable robots to work effectively in real time in an unstructured environment, one needs to solve repeatedly a variety of highly complex mathematical problems such as on-line planning, vision, sensor fusion, navigation, manipulator dynamics and control. The computational requirements of most of these problems fall into the "supercomputer" class, but ultimately one needs to process them "onboard" the autonomous machine. Currently, the only realistic option is VLSI-based concurrent computation. This paper builds on the recent development of a VLSI hypercube supercomputer, to address the fundamental issue of implementing

robotic algorithms on actual concurrent hardware.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

*University of Tennessee, Knoxville, TN.

4.13

ROBOTICS APPLICATIONS ON AN ADVANCED HYPERCUBE MULTIPROCESSOR: INITIAL DEVELOPMENTS

**J. Barhen M. C. G. Hall
J. R. Einstein**

(Abstract of paper presented at the IEEE Workshop on Special Computer Architectures for Robot Control, 1986 International Conference on Robotics and Automation, San Francisco, CA, April 7-10, 1986; Proc. pp. 3.1-3.7, April 1986)

Specialized computer architectures for advanced robotics applications at ORNL/CESAR are based on the hypercube ensemble concept. We summarize the current status of algorithm development and present results for robot dynamics and navigation problems.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

4.14

THE HYPERCUBE IN ROBOTICS AND MACHINE INTELLIGENCE

J. Barhen J. F. Palmer*

(Abstract of *Computers in Mech. Eng. J.* 4(5), 30 (1986))

The advent of VLSI technology and its implementation in the design of advanced computer systems involving a high degree of concurrency is opening tremendous opportunities for a wide spectrum of applications which require "supercomputing" capabilities. In this context we present the NCUBE supersystem, a revolutionary advance in the expanding domain of concurrent computation machines. This system, designed from the ground up to be optimally implemented in state-of-the-art VLSI, provides unmatched performance and reliability, yet is extremely com-

pact in size. Critical issues in the development of algorithms for such a message-passing hypercube architecture are addressed, particularly with respect to load balancing, or optimal resource utilization. Potential implications for the areas of machine intelligence and robotics are discussed, with emphasis on computer vision and manipulator inverse dynamics.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*NCUBE Corporation, Beaverton, OR.

4.15

CONCURRENT NEUROMORPHIC ALGORITHMS FOR OPTIMIZATION OF THE COMPUTATIONAL LOAD OF A HYPERCUBE SUPERCOMPUTER

**J. Barhen V. Protopopescu
N. Toomarian M. Clinard***

(Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, June 21-24, 1987)

A novel approach toward the optimization of the time-dependent computational load in message-passing multiprocessor systems is presented. Compact neuromorphic data structures are used to model effects such as precedence constraints, processor idling time and task-schedule overlap. Analytic expressions are given for the effect of single-neuron perturbations on the systems' configuration energy. Algorithms for the implementation of this methodology on a hypercube supercomputer are outlined along with potential extensions to large-scale nonlinear asynchronous neural networks.

Research sponsored by U.S. DOE Office of Military Applications and Engineering Research Program.

*University of Tennessee, Knoxville, TN.

4.16

OPTIMIZATION OF THE COMPUTATIONAL LOAD OF A HYPERCUBE SUPERCOMPUTER ONBOARD A MOBILE ROBOT

**J. Barben N. Toomarian
V. Protopopescu**

[Abstract of *Applied Optics* (in press)]

A combinatorial optimization methodology is developed, which enables the efficient use of hypercube multiprocessors onboard mobile intelligent robots dedicated to time-critical missions. The methodology is implemented in terms of large-scale concurrent algorithms based either on fast simulation annealing or on nonlinear asynchronous neural networks. In particular, analytic expressions are given for the effect of single-neuron perturbations on the systems' configuration energy. Compact neuromorphic data structures are used to model effects such as precedence constraints, processor idling times and task-schedule overlaps. Results for a typical robot-dynamics benchmark are presented.

Research sponsored by U.S. DOE Office of Military Applications and Engineering Research Program and by U.S. Air Force Wright Aeronautical Laboratories.

4.17

ON THE STABILITY, STORAGE CAPACITY, AND DESIGN OF NONLINEAR CONTINUOUS NEURAL NETWORKS

**A. Guez* V. Protopopescu
J. Barben**

[Abstract of ORNL/TM-10329, February 1987; also IEEE Trans. on Systems, Man, and Cybernetics (in press)]

The stability, capacity, and design of a nonlinear, continuous neural network are analyzed. Sufficient conditions for existence and asymptotic stability of the network's equilibria are reduced to a set of piecewise linear inequality relations which can be solved by a feedforward binary network, or by methods such as Fourier Elimination. The stability and capacity of the network is characterized by the postsynaptic firing rate func-

tion. An N neuron network with sigmoidal firing function is shown to have up to 3^N equilibrium points of which $N+1$ arbitrary points may always be made stable. This offers a higher capacity than the $(0.1-0.2)N$ obtained in the binary Hopfield network. Moreover, it is shown that by a proper selection of the postsynaptic firing rate function, one can significantly extend the capacity storage of the network.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratories and by U.S. DOE Office of Military Applications and Office of Basic Energy Sciences.

* Drexel University, Philadelphia, PA.

4.18

THE PEBBLE CRUNCHING MODEL FOR ADAPTIVE LOAD BALANCING IN HYPERCUBE COMPUTATION ENSEMBLES

**S. Gulati* J. Barben
S. S. Iyengar***

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

The successful development of fifth generation supercomputing systems for strategic defense missions, autonomous robots and large scale AI applications requires enormous computational capability and flexibility. Of fundamental consideration for these applications is the ability to achieve operational responses in real-time through optimal resource utilization and introduction of adaptive control into selected control functions. These objectives entail dynamically balancing the computational load among all the processing nodes in the system. This paper proposes a two-tiered fault-tolerant, graph-theoretic algorithm for adaptive load balancing in large-scale hypercube computation ensembles.

The algorithm is proved to be correct and deadlock free. It is shown that this model results in an increased system throughput and resource utilization. The discussion also includes implementation details and performance analysis for the algorithm implemented on the 64-node, NCUBE hypercube.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Louisiana State University, Baton Rouge, LA.

4.19

NONLINEAR NEURAL NETWORK FOR DETERMINISTIC SCHEDULING

S. Gulati* S. S. Iyengar*
N. Toomarian V. Protopopescu
J. Barben

(Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, June 21-24, 1987)

This paper addresses the NP-complete, deterministic scheduling problem for a uniprocessor system using an additive nonlinear neural network. Given a set of N tasks along with the precedence-constraints among them, the timing requirements for each task, and their completion due dates, the model is used to construct a non-preemptive optimal processing schedule such that the total completion time, total lateness and number of late jobs are minimized. This modeling strategy exhibits faster convergence than combinatorial techniques based on simulated annealing. The scheduling schema is then extended to generate a preemptive schedule for the tasks. As the constraint domain is enhanced, it is observed that the use of symmetric matrices to represent neural interconnections is highly space inefficient, as these matrices are normally sparse for the scheduling problem. This issue calls for an exploration of alternate data structures, a discussion of which is included.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Louisiana State University, Baton Rouge, LA.

4.20

CATCHING KNOWLEDGE IN NEURAL NETS

C. C. Jorgensen C. Matheus*

[Abstract of *AI Expert* 1(1), 30 (1986)]

This article is an overview of neural networks. The paper includes their history, how they work, who is active in the area, and gives sample programs showing how a Hopfield network and

Boltzmann machine can be constructed. It was the cover article for *AI Expert* in December 1986.

*University of Illinois, Urbana, IL.

4.21

CONCURRENT ALGORITHMS FOR AUTONOMOUS ROBOT NAVIGATION IN AN UNEXPLORED TERRAIN

N. S. V. Rao* S. S. Iyengar*
C. C. Jorgensen C. R. Weisbin

[Abstract of paper presented at the IEEE 1986 International Conference on Robotics and Automation, San Francisco, CA, April 7-10, 1986; Proc. Vol. 2, p. 1137 (1986)]

Navigation planning is one of the vital aspects of any autonomous mobile robot. In this paper, we present concurrent algorithms for an autonomous robot navigation system that does not require a pre-learned obstacle terrain model. The terrain model is gradually built by integrating the information from multiple journeys. The available information is used to the maximum extent in navigation planning, and global optimality is gradually achieved. It is shown that these concurrent algorithms are free from deadlocks and starvation. The performance of the concurrent algorithms is analyzed in terms of the planning time, travel time, scanning time, and update time. A modified adjacency list is proposed as the data structure for the spatial graph that represents an obstacle terrain. The time complexities of various algorithms that access, maintain, and update the spatial graph are estimated, and the effectiveness of the implementation is illustrated.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Louisiana State University, Baton Rouge, LA.

4.22

A CONCURRENT NEURAL NETWORK ALGORITHM FOR THE TRAVELING SALESMAN PROBLEM

N. Toomarian

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

A binary neuromorphic data structure is used to encode the N-City Traveling Salesman Problem (TSP). In this representation the computational complexity, in terms of number of neurons required is reduced from Hopfield and Tank's $O[N^2]$ to $O[N \log_2 N]$. A continuous synchronous neural network algorithm, implemented on the NCUBE hypercube, is used to solve the problem. This algorithm converges faster and has a higher probability to reach a valid tour than previously available results. The paper also presents comparisons with simulated annealing approaches.

Research sponsored by U.S. DOE Office of Military Applications and by the Engineering Research Program.

4.23

NEUROMORPHIC ALGORITHMS FOR THE SOLUTION OF THE TRAVELING SALESMAN PROBLEM ON A HYPERCUBE

N. Toomarian

(Abstract of paper to be presented at the ORSA/TIMS Meeting, St. Louis, MO, October 25-28, 1987)

Parallel algorithms for the simulation of large-scale nonlinear continuous neural networks on a hypercube supercomputer are developed. These algorithms are applied to solve optimization problems of combinatorial complexity such as the traveling salesman problem, multiprocessor scheduling and load balancing. Results indicate a significant improvement in performance over techniques based on simulated annealing for these complex problems.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

Planning, Problem Solving, and Learning

4.24

AUTONOMOUS NAVIGATION, EXPLORATION AND RECOGNITION USING THE HERMIES-IIB ROBOT

B. L. Burks G. de Saussure
C. R. Weisbin J. P. Jones
W. R. Hamel*

[Abstract of *IEEE Expert* (in press); also paper entitled, "Dealing with Unanticipated Events in Autonomous Navigation," by B. L. Burks, D. L. Barnett, S. M. Killough, R. C. Mann, and F. G. Pin, to be presented at the 26th IEEE Conference on Decision and Control, Los Angeles, CA, December 9-11, 1987]

In this paper, we describe advances to our mobile robot series (currently HERMIES-IIB) to include 8 NCUBE processors onboard (computationally equivalent to 8 Vax 11/780's) operating in parallel, and augmentation of the sensor suite with cameras to facilitate on-board vision analysis and goal finding. The essential capabilities of the

expert system described in our earlier paper have also been ported to the on-board HERMIES-IIB computers thereby eliminating off-board computation. We described a successful experiment in which a robot is placed in an initial arbitrary location without prior specification of the room contents, successfully discovers and navigates around stationary and occasionally moving obstacles, picks up and moves small obstacles, searches for a control panel, and reads the meters found on the panel. The success of this experiment encourages more complex on-board vision analysis and expert system control in dynamic environments. The experiment will be expanded to include research in robot learning as the robot attempts to adjust the meter reading to a particular value without *a priori* knowledge of the control panel system dynamics.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division

†Computing and Telecommunications Division

4.25

A REAL-TIME EXPERT SYSTEM FOR THE CONTROL OF AUTONOMOUS ROBOT NAVIGATION IN THE PRESENCE OF MOVING OBSTACLES

**G. de Saussure D. W. Kammer*
C. R. Weishin**

[Abstract of paper presented at the American Nuclear Society International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, WA, March 29 — April 2, 1987; Proc. p. 298 (1987); also paper entitled "A Real-Time Expert System for Control of an Autonomous Mobile Robot and for Diagnosing Unexpected Occurrences" presented at the Workshop on Automation and Robotics for Military Application, Huntsville, AL, October 22-23, 1986]

The use of an expert system for the control of an autonomous robot presents several attractive features: the explicitness and homogeneity of the knowledge representation facilitates explanation, verification and modification of the rules which determine the robot's behavior, and the domain of competence can be incrementally extended. However, real-time operation poses a number of challenges due to the dynamic nature of the data and the time constraints of dealing with a large data base.

An implementation is discussed where a large commercial real-time expert system originally designed for industrial process diagnostics was adapted to the control of an autonomous mobile robot for planning, monitoring, and diagnosis of unexpected occurrences during a navigation task. Control has been successfully implemented for goal directed navigation in the presence of moving obstacles.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Albion College, Albion, MI.

4.26

A REAL-TIME PRODUCTION SYSTEM FOR INTELLIGENT ROBOT CONTROL

**G. de Saussure D. W. Kammer*
C. R. Weishin**

(Abstract of paper presented at the National Conference on Artificial Intelligence, Philadelphia, PA, August 11-15, 1986)

The use of a production system for the control of an autonomous robot presents several attractive features: the explicitness and homogeneity of the knowledge representation facilitates explaining, verifying and modifying the rules which determine the robot's behavior; it also permits the incremental extension of the domain of competence. However, real-time operation poses a number of challenges due to the dynamic nature of the data and because the system must frequently deal with a large knowledge base in a limited time. An implementation of a knowledge base is discussed where a large commercial real-time expert system originally designed for industrial process diagnostic was adapted to the control of an autonomous mobile robot planning, executing and monitoring a set of navigational tasks.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Albion College, Albion, MI.

4.27

A VIRTUAL-TIME OPERATING-SYSTEM SHELL FOR THE NCUBE HYPERCUBE

J. R. Einstein

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

Hypercube multiprocessors used in autonomous robots carrying out time-critical tasks in unpredictable environments require special operating system functions to provide the capability of rapid response to unforeseen external events. The use of distributed memory and

message-passing makes the hypercube highly scalable, but presents difficulties for rapid responses.

Efficient response to unforeseen events requires the addition to the node's operating system of a shell which implements cancellation messages, correction messages, emergency messages, and the restoration of temporal logic by ordering input messages to a node according to their timestamps.

An initial version of a "virtual-time" (VT) shell having the above functions has been added to the Vertex operating system of the NCUBE computer. The shell modifies the Vertex interrupt-driven input-message handler, which originally implemented a FIFO queue, so as to accomplish the functions listed above. These include in-queue correction and cancellation of messages. Another feature of the shell is the option rollback of the application program to a previous state when a correction/cancellation message arrives too late for in-queue action. The status of these features and of a test bed to exercise all functions will be discussed.

Research sponsored by U.S. DOE Office of Military Applications, Joint DOE/SDIO Innovative Concepts Program.

4.28

ROBOT CONTROL WITH A HYPERCUBE: VIRTUAL-TIME FUNCTIONS FOR THE NODE'S OPERATING SYSTEM

J. R. Einstein J. Barben

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

Use of a multiprocessor such as a VLSI-based hypercube can potentially provide enormous computing power as required in controlling an autonomous robot in an unpredictable environment. However, given a number of complex activities (for planning, sensors, control of effectors), each distributed over a number of nodes, problems arise in rapid response to unpredictable events and in conserving temporal logic.

Among the streams of messages passing between the various activities and between each

activity's subtasks, many refer to future real time or to sequences of events in future real time. In an unpredictable environment, the robot "planner" must often change plans on receiving new sensor information. Therefore, at any node, we expect a stream of messages including corrections and cancellations of previous messages. These messages may arrive out of their intended time order for several reasons, including unpredictable routing delays.

For efficiency, certain functions must be part of the node's operating system: correction or cancellation of messages still in the input queue, and ordering these messages in time. Analogous functions are used in the Time Warp methodology of Jefferson and Sowizral for discrete-event simulation. For an event-driven system, other necessary functions include starting tasks on receipt of their input messages, starting them in "correction mode" on receipt of correction or cancellation messages which have arrived too late, and implementing emergency messages capable of interrupting any task. Most of these operating system functions have been developed with the use of a hypercube simulator on a VAX. We will report on the status of their implementation within the Vertex (node) operating system of the NCUBE hypercube.

Research sponsored by the U.S. Air Force Wright Aeronautical Laboratories.

4.29

INTELLIGENT OPERATING SYSTEMS FOR AUTONOMOUS ROBOTS: REAL-TIME CAPABILITIES ON A HYPERCUBE SUPERCOMPUTER

J. R. Einstein J. Barben
D. Jefferson*

[Abstract of paper presented at the American Nuclear Society International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, WA, March 29 - April 2, 1987; Proc. p. 127 (1987)]

Autonomous robots which must perform time-critical tasks in hostile environments require computers which can perform many asynchronous tasks at extremely high speeds. Certain hypercube multiprocessors have many of the required

attributes, but their operating systems must be provided with special functions to improve the capability of the system to respond rapidly to unpredictable events. A "virtual-time" shell, under design for addition to the Vertex operating system of the NCUBE hypercube computer, and having such capabilities, is described.

Research sponsored by U.S. DOE Office of Military Applications and Office of Basic Energy Sciences.

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4.30

A VIRTUAL-TIME OPERATING SYSTEMS SHELL FOR A HYPERCUBE IN ROBOTICS APPLICATIONS

**J. R. Einstein J. Barhen
D. Jefferson***

[Abstract of paper presented at the SPIE Cambridge Symposium on Optical and Optoelectronic Engineering, Cambridge, MA, October 26-31, 1986; Proc. SPIE Vol. 729, Space Station Automation II, p. 424 (1986)]

Hypercube multiprocessors possess many attributes advantageous for autonomous, intelligent robots which operate in time-critical fashion in hostile environments. However, their message-passing architecture presents certain difficulties in rapid changes of plans in response to unpredictable events in the environment. The status of a "virtual-time" operating-system shell, providing functions which facilitate such responses, is described.

Research sponsored by U.S. DOE Office of Military Applications and Office of Basic Energy Sciences.

*University of California at Los Angeles, Los Angeles, CA.

4.31

VIRTUAL-TIME OPERATING-SYSTEM FUNCTIONS FOR ROBOTICS APPLICATIONS ON A HYPERCUBE

**J. R. Einstein J. Barhen
D. Jefferson***

[Abstract of paper presented at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia, p. 100 (1987)]

When a hypercube is used to control an autonomous robot, there are streams of messages passing between the various activities (for planning, sensors, effectors) and between each activity's subtasks (generally mapped onto a number of nodes). Many messages refer to future real time or to sequences of events in future real time. In an unpredictable environment, the robot "planner" must often change plans on receiving new sensor information. Therefore, at any node, we expect a stream of messages including corrections and cancellations of previous messages. These messages may arrive out of their intended time order for several reasons, including unpredictable routing delays.

For efficiency, certain functions must be part of the node's operating system: correction or cancellation of messages still in the input queue, and ordering these messages in time. Analogous functions are used in the Time Warp methodology of Jefferson and Sowizral for discrete-event simulation. For an event-driven system, other necessary functions include starting tasks on receipt of their input messages, starting them in "correction mode" on receipt of correction or cancellation messages which have arrived too late, and implementing emergency messages capable of interrupting any task. Most of these operating system functions have been developed with the use of a hypercube simulator on a VAX. We will report on the status of their implementation within the Vertex (node) operating system of the NCUBE hypercube.

Research sponsored by the U.S. Air Force Wright Aeronautical Laboratories.

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4.32

ROBOT NAVIGATION ALGORITHMS USING LEARNED SPATIAL GRAPHS

S. S. Iyengar* C. C. Jorgensen
S. V. N. Rao* C. R. Weisbin

[Abstract of ORNL/TM-9782, December 1985; also *Robotica* 4, 93 (1986); also paper entitled "Learned Navigation Paths for a Robot in Unexplored Terrain," presented at the Second Conference on Artificial Intelligence Applications, the Engineering of Knowledge-Based Systems, IEEE Computer Society, Miami Beach, FL, December 11-13, 1985; Proc. p. 148 (1985)]

Finding optimal paths for robot navigation in known terrain has been studied for some time but, in many important situations, a robot would be required to navigate in completely new or partially explored terrain. We propose a method of robot navigation which requires no pre-learned model, makes maximal use of available information, records and synthesizes information from multiple journeys, and contains concepts of learning that allow for continuous transition from local to global path optimality. The model of the terrain consists of a spatial graph and a Voronoi diagram. Using acquired sensor data, polygonal boundaries containing perceived obstacles shrink to approximate the actual obstacles' surfaces, free space for transit is correspondingly enlarged, and additional nodes and edges are recorded based on path intersections and stop points. Navigation planning is gradually accelerated with experience since improved global map information minimizes the need for further sensor data acquisition. Our method currently assumes obstacle locations are unchanging, navigation can be successfully conducted using two-dimensional projections, and sensor information is precise.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Louisiana State University, Baton Rouge, LA.

4.33

NEURAL NETWORK REPRESENTATION OF SENSOR GRAPHS IN AUTONOMOUS ROBOT PATH PLANNING

C. C. Jorgensen

(Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, June 21-24, 1987)

This paper discusses a continuous valued associative neural network used for anticipatory robot navigation planning in partially learned environments. A navigation methodology is implemented in four steps. First, a room is represented as a lattice of connected voxels formed by dividing navigation space into equal sized volumetric cells. Each voxel is associated with a simulated neuron. The magnitude of a neurons activation corresponds to a probability of voxel occupancy calculated from a series of sonar readings taken by an autonomous robot. Neurons are trained with a series of room patterns derived from varying robot sensor perspectives. At another time, the robot is exposed to a single perspective of one of the rooms and utilizes the sensor return as a cue to prompt associative recall of a best guess of the complete interior of the room. A two step path planning operation is then invoked which uses line of sight readings and anticipated global information to form a trial path plan. The planning process merges a nearest neighbor grid cell technique and a simulated annealing gradient descent method to optimize traversal movements. In the final step, the path is followed until a mismatch between the estimated room and the actual sensor returns indicate incorrect anticipation. Implementation of the method on a Hypercube computer is discussed along with memory computation tradeoff requirements.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.34

NEURAL NETWORK RECOGNITION OF ROBOT SENSOR GRAPHS USING HYPERCUBE COMPUTERS

C. C. Jorgensen

[Abstract of oral presentation given at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986 (full paper not submitted for proceedings)]

Simulated neural networks such as those proposed by Hopfield, Fukayama, or Pollack have led to interest in the application of a network's inherent pattern recognition capabilities to real world situations. For example, robot utilization of sensor data leads to many situations where inherently fuzzy pattern environments must be matched to internal knowledge representations such as those used to navigate in unstructured or changing environments. The resistance of neural network formulations to noise and their ability to learn makes such approaches attractive options for consideration. Unfortunately network models also impose heavy computational requirements in applications with high data band widths such as vision or sonar signal interpretation.

This paper presents the first results of an effort to implement a modified form of a Hopfield network using an NCUBE machine. The network receives as input sensor distance data from sonar transducers on a small mobile robot called HERMIES-II. Preliminary identifications of generic room environments are made by the application of the network in both a learning and pattern recognition mode. The room environment is encoded as a 3600 element state relationship vector of sonar distance readings during a series of learning trials. Associated with each state vector is a label vector. Generic sensory maps are formed in the Hopfield net as a result of repeated exposures to sonar distance vectors. Recall then takes place through the exposure of the net to a new sensor reading from one of the generic room situations and the results are determined from the generated pattern label. This work will eventually be expanded to consider visual pattern inputs and utilize the result of the memory queries to guide higher order robot navigation decisions.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.35

CONTROL ALGORITHMS FOR AUTONOMOUS ROBOT NAVIGATION

C. C. Jorgensen

[Abstract of paper presented at the ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville, TN, April 20-24, 1986; Proc. p. 100 (April 1986)]

This paper examines control algorithm requirements for autonomous robot navigation outside laboratory environments. Three aspects of navigation are considered: navigation control in explored terrain, environment interactions with robot sensors, and navigation control in unanticipated situations. Major navigation methods are presented and relevance of traditional human learning theory is discussed. A new navigation technique linking graph theory and incidental learning is introduced.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.36

EXPLORING AUTONOMOUS ROBOT NAVIGATION

C. C. Jorgensen C. R. Weisbin
W. R. Hamel*

[Abstract of Byte 11(1), 223 (1986)]

In recent years robotic devices have rapidly grown in sophistication. One aspect of this growth has been interest in transitioning from jobs in carefully controlled fixed environments to flexible multipurpose tasks with mobile operations. The result has been a dramatic increase in research dealing with the development of machine intelligence autonomous robots and in particular the integration of robot sensors and control algorithms. Evolving from a fixed, repetitive robot on an assembly line to the self motivated R2-D2 of Star Wars requires technical advances in a variety of areas including power supply systems, sensor interpretation, computer architectures, dynamics and control, and planning. One particularly important area is navigation. Navigation generally deals with how a robot would explore

previously unlearned environments and plan movements through those environments to attain higher level goals. This article considers some of the navigation problems which must be dealt with by an autonomous robot.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

4.37

A REAL-TIME EXPERT SYSTEM FOR ROBOTIC TASK PLANNING, MONITORING AND DIAGNOSIS OF UNEXPECTED OCCURRENCES

**D. Kammer* G. de Saussure
C. R. Weisbin**

(Abstract of paper presented at the 1986 Conference on Intelligent Systems and Machines, Center for Robotics and Advanced Automation, Oakland University, Rochester, MI, April 29-30, 1986)

A large expert system, initially designed for industrial process control, has been modified to serve as the "brain" for an autonomous mobile robot. The advantages of a product-rule knowledge base for robot plan generation have recently been underscored by R. P. Sobek.

Several efforts are underway to design robot planning programs using production rules, but, to our knowledge no robot has been actually controlled by an expert system.

To implement this approach, a large real-time expert system, PICON (Process Intelligent Control), originally designed for industrial process diagnosis and control, has been adapted to guide the autonomous mobile robot HERMIES using sonar transducers as sensors. PICON has been described by R. L. Moore *et al.*. It consists essentially of a LISP-written dynamic expert system and of a C-written interface module, RTIME. Both programs are run asynchronously and in parallel on separate processors with several communication links between them.

Since PICON was designed for process control (or more precisely in the present B-test initial version, for process diagnosis) extensive modifications had to be done on the system to adapt it to

the tasks of robot plan generation and robot control. Such modifications are particularly challenging because of the dynamic nature of the production rules and of the sensor data and because the delicate overall timing of the system and the communication protocols must be preserved.

In our implementation RTIME handles routine tasks such as communications via an RF link with an 8088 processor onboard the robot, sensor data analysis, path planning and unusual condition sensing while PICON handles the operator interface, status monitoring, operation sequencing and problem diagnosis. RTIME continually monitors the communication channels between it and PICON for commands and passes to PICON information on the status of its operations. In addition, RTIME passes information on unexpected occurrences deduced from sensor data to PICON for high level analysis and waits for commands on how to intelligently react to these events. Because PICON's rule structure provides for periodic rule scanning along with automatic data updating and an alert facility which automatically activates rules based on data from RTIME, it is especially well suited to deal with unanticipated events. In this way, each part of the system is given tasks to which it is best suited.

In conclusion, we have successfully demonstrated that a commercial dynamic expert system may be adapted to controlling a robot. At present we are designing algorithms to guide the robot through a succession of progressively more sophisticated planning, navigation and monitoring tasks.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Albion College, Albion, MI.

4.38

THE VISIT PROBLEM: VISIBILITY GRAPH-BASED SOLUTION

N. S. V. Rao* S. S. Iyengar*
G. de Saussure

(Abstract of paper to be presented at the 1988 IEEE International Conference on Robotics and Automation, Philadelphia, PA, April 25-29, 1988)

The *visit problem* is defined as follows: a circular body R is located at point d_0 in a finite-sized two-dimensional terrain populated by a finite number of polygonal obstacles; each obstacle has a finite number of vertices. The R is equipped with a sensor system capable of detecting all vertices and edges seen from its present location. A computing device with storage capability is also housed on R . Initially, the R is located at a point d_0 , and *no terrain model is available to R* . The R is capable of translational motion. The R is required to execute a navigational mission which involves visiting a sequence of the destination points, namely, $d_1, d_2, \dots, d_M$, in the specified order. We present the algorithm LNAV that navigates R from d_i to d_{i+1} . We prove the correctness of this algorithm, and also estimate its performance in terms of the number of scan operations, the distance traversed and the computational complexity. We then present the algorithm GNAV that executes the navigational mission. It uses LNAV in traversing in between successive destination points in the mission and builds a global visibility graph of the terrain by integrating the sensor information obtained over a period of time as R keeps navigating. We validate and analyze the algorithm GNAV. We also illustrate that, in a general case of executing a navigation mission, the performance using GNAV is more efficient than the repeated application of LNAV in terms of number of scan operations and the distance traversed by R .

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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4.39

ROBOT NAVIGATION IN AN UNEXPLORED TERRAIN

N. S. V. Rao* S. S. Iyengar*
C. C. Jorgensen C. R. Weisbin

[Abstract of *J. Robotic Systems* 3(4), 389 (1986)]

Navigation planning is one of the most vital aspects of an autonomous mobile robot. Robot navigation for completely known terrain has been solved in many cases. Comparatively less research dealing with robot navigation in unexplored obstacle terrain has been reported in the literature. In recent times this problem has been addressed by adding learning capability to a robot. The robot explores terrain using sensors as it navigates and builds a terrain model in an incremental manner. In this article we present concurrent algorithms for robot navigation in unexplored terrain. The performance of the concurrent algorithms is analyzed in terms of planning time, travel time, scanning time, and update time. The analysis reveals the need for an efficient data structure to store an obstacle terrain model in order to reduce traversal time, and also to incorporate learning. A modified adjacency list is proposed as a data structure for storing a spatial graph that represents an obstacle terrain. The time complexities of the algorithms that access, maintain, and update the spatial graph are estimated, and the effectiveness of the implementation is illustrated.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

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4.40

ON TERRAIN ACQUISITION BY A FINITE-SIZED MOBILE ROBOT IN PLANE

N. S. V. Rao* S. S. Iyengar*
C. C. Jorgensen C. R. Weisbin

[Abstract of paper presented at the 1987 IEEE International Conference on Robotics and Automation, Raleigh, NC, March 30 - April 3, 1987; Proc. Vol. 3, p. 1314 (1987)]

The terrain acquisition problem deals with the acquisition of the complete obstacle terrain model by a mobile robot placed in an unexplored terrain. This is a precursory problem to many well-known find-path and related problems which assume the availability of the complete terrain model. In this paper, we present a method for terrain acquisition by a finite sized robot operating in plane populated by an unknown (but finite) number of polygonal obstacles; each obstacle is arbitrarily located and has unknown (but finite) number of vertices. The robot progressively explores newer vertices of the obstacles using sensor equipment. We show that the complete terrain model will be built by the robot in a finite time. We also show that at any point of time the partially acquired terrain suffices for the navigation of the robot during the exploration. Hence we conclude that the navigation techniques for known terrains can be applied for the robot navigation during exploration.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Louisiana State University, Baton Rouge, LA.

4.41

ON AUTONOMOUS TERRAIN MODEL ACQUISITION BY A MOBILE ROBOT

N. S. V. Rao* S. S. Iyengar*
C. R. Weisbin

(Abstract of paper presented at a Workshop on Space Telerobotics, California Institute of Technology, Pasadena, CA, January 20-23, 1987)

In this paper we consider the following problem: A point robot is placed in a terrain popu-

lated by unknown number of polyhedral obstacles of varied sizes and locations in two/three dimensions. The robot is equipped with a sensor capable of detecting all the obstacle vertices and edges that are visible from the present location of the robot. The robot is required to autonomously navigate and build the complete terrain model using the sensor information. We establish that the necessary number of scanning operations needed for complete terrain model acquisition by any algorithm that is based on 'scan from vertices' strategy is given by $\sum_{i=1}^n N(O_i) - n$ and $\sum_{i=1}^n N(O_i) - 2n$ in two and three dimensional terrains respectively, where $O = \{O_1, O_2, \dots, O_n\}$ is the set of the obstacles in the terrain, and $N(O_i)$ is the number of vertices of the obstacle O_i .

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Louisiana State University, Baton Rouge, LA.

4.42

SENSOR-BASED MODELING, LEARNING AND COPING WITH UNSCHEDULED EVENTS

C. R. Weisbin

(Abstract of paper presented at the 1987 WATtec Conference on Perspectives in Global Competitiveness, Quality, Productivity, and Innovation, Knoxville, TN, February 17-20, 1987)

Almost all of the disciplines which together constitute what many perceive as "artificial intelligence" can be used to great advantage within nuclear facilities. These disciplines include natural language understanding, speech recognition and synthesis, computer vision, multi-sensor integration, search, inference, expert systems, learning, etc. The scope of this presentation is narrowly focused toward methods for dealing with unexpected events, learning from experience, and efficiently modeling a three-dimensional (3-D) world. This research is particularly germane to robot navigation and surveillance in dynamic environments. The presentation reports upon the research performed by members of the Center for Engineering Systems Advanced Research (CESAR) staff of the Oak Ridge National Laboratory.

de Saussure *et al.* have extended the capabilities of the PICON expert system to deal with dynamic replanning due to unforeseen events. The HERMIES robot series has been used as a testbed and actual experimental results will be shown. Iyengar *et al.* have described a methodology for the systematic improvement of path planning capability used upon experience from previous journeys. Experimental testing of these learning procedures is now underway. In each of the studies described above, the actual algorithm deals with a two-dimensional representation. Goldstein *et al.* have developed an approach for description of a changing three-dimensional world using methods of combinatorial geometry applied to discrete range information. The algorithms have been verified and appear most promising. Actual implementation of the HERMIES robot is planned in the near future. Each of the three research investigations mentioned above will be discussed.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Nuclear Energy.

4.43

REAL-TIME CONTROL: A SIGNIFICANT TEST OF AI TECHNOLOGIES

C. R. Weisbin

[Abstract of Guest Editor's Introduction, *IEEE Expert J.* (in press)]

For some time now, scientists have successfully applied AI methodologies to problems of classification, scheduling, and learning in environments whose characteristics are known *a priori*. A more stringent test of AI, however, is the real-time control of autonomous robots (1) to reduce human error through the automation of repetitive, dull, and routine tasks, (2) to minimize human risk by enabling effective remote operation in hazardous environments, and (3) to cope effectively with emergency situations requiring rapid response. These closed-loop problem settings where the human serves as supervisor stress such factors as dynamic replanning, swift decision making under uncertainty, and powerful on-board computational capability.

Research sponsored by U.S. DOE Office of Basic Energy Sciences

4.44

A REAL-TIME EXPERT SYSTEM FOR AN AUTONOMOUS MOBILE ROBOT

C. R. Weisbin G. de Saussure
D. W. Kammer*

[Abstract of *Computers in Mech. Eng.* 5(2), 12 (1986); also paper entitled, "A Real-Time Expert System for Control of an Autonomous Mobile Robot Including Diagnosis of Unexpected Occurrences," presented at SPIE Cambridge Symposium on Optical and Optoelectronic Engineering, Cambridge, MA, October 26-31, 1986; Proc. SPIE Vol. 729, Space Station Automation II, p. 49 (1986)]

An autonomous mobile robot deals with the empirical world which is never fully predictable, hence it must continually monitor its performance by comparing the actual responses of sensors to their expected responses. Where a discrepancy occurs, the source of the discrepancy must be diagnosed and on-line corrective actions or replanning may be required.

The use of a production system for the control of an autonomous robot presents several attractive features: the explicitness and homogeneity of the knowledge representation facilitates explaining, verifying and modifying the rules which determine the robot's behavior; it also permits the incremental extension of the domain of competence. However, real-time operation poses a number of challenges due to the dynamic nature of the data and because the system must frequently deal with a large knowledge base in a limited time.

An implementation of a control system is discussed where a large commercial real-time expert system originally designed for industrial process diagnostics was adapted to the control of an autonomous mobile robot for planning, executing and monitoring a set of navigational tasks. One of the essential components of the problem domain is the occurrence of an "unexpected" happening, e.g., as new obstacles are moved into the domain during the robot traverse, or when an obstacle undetectable by the long-range sonar sensors is suddenly observed by a proximity sensor. In a recent demonstration of the system, the detection of a problem generated an interrupt alarm, a diagnostic procedure, and a new plan, which was successfully executed in real time.

Research sponsored by U.S. DOE Office of Basic Energy Sciences

*Albion College, Albion, MI

Vision and Multisensor Integration

4.45

A CONCURRENT MULTI-SENSOR INTEGRATION PROGRAM

C. W. Glover

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

This presentation describes the design and implementation of multi-sensor integration (MSI) algorithm on the ORNL computer. The goal of the MSI algorithm is to synergistically combine sensor measurements to provide a single estimate of the environmental state space (i.e., estimate the number of objects in the environment, kinematics and identification of each object). This state space information can then be used by other algorithms to perform other tasks (e.g., robot navigation, sensor allocation, etc.). The MSI algorithm can be segmented into parts which perform common referencing for all sensor measurements, the intersensor correlation of all measurements (reports), the evaluation of the intersensor report correlation hypotheses, selection of the most likely hypothesis, and updating the state space estimate based on the most likely data association. MSI software, which incorporates these segments, has been implemented on the NCUBE hypercube and will be described in detail.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratory.

4.46

A CONCURRENT ON-BOARD VISION SYSTEM FOR A MOBILE ROBOT

J. P. Jones

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

This paper describes an integration of robot vision algorithms on an 8-node NCUBE-AT hypercube system on board a mobile robot

(HERMIES) developed at Oak Ridge National Laboratory. The vision system is interfaced to navigation and robot control software, enabling the robot to find the front of a mock-up control panel, move up to the panel, and read an analog meter. It is assumed that there are no obstacles between the robot and the panel. The vision system uses two calibrated cameras with different focal length lenses. Distance information is inferred from *a priori* knowledge of relative sizes of objects in the scene. Images are digitized using Datacube hardware mounted in a VME system on board HERMIES.

Among the concurrent algorithms used in this experiment are a new component labeling algorithm and a Hough transform algorithm with load balancing which will be described in detail.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Technology Support Programs.

4.47

IMAGE PROCESSING ON A HYPERCUBE CONCURRENT MULTIPROCESSOR

J. P. Jones

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

Computational problems in image processing and the early stages of artificial vision are typified by a highly regular structure. One typically wishes to compute metrics concerning a limited region of an image over many identical regions. Convolution with linear filters for edge detection is an example of such a computation. Because concurrent computers promise greatly increased throughput, image processing and artificial vision are areas in which we can expect parallel and concurrent processors to find wide application. The vision research program at the Center for Engineering Systems Advanced Research (CESAR) has focussed on the use of the NCUBE hypercube concurrent computer as a research tool. To date, we have implemented several algorithms for low-level vision and image processing.

including edge detection in laser range finder data, convolution, a local contrast enhancement algorithm, and two-dimensional fast Fourier transforms. We are currently benchmarking these and other algorithms for the purpose of comparison with alternate technologies.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratories.

4.48

APPLICATION OF THE NCUBE HYPERCUBE CONCURRENT PROCESSOR TO IMAGE PROCESSING AND ARTIFICIAL VISION

J. P. Jones

[Abstract of oral presentation given at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986 (full paper not submitted for proceedings)]

Computational problems in early vision are characterized by a highly regular structure. One typically wishes to compute metrics concerning a limited region of an image over many identical regions. Convolution with linear filters for edge detection is an example of such a computation. Because concurrent computers promise greatly increased throughput, vision is one area in which we can expect parallel and concurrent processors to find wide application. The vision research program at the Center for Engineering Systems Advanced Research (CESAR) has focussed on the use of the NCUBE hypercube concurrent computer as a research tool. To date, we have implemented several algorithms for low level vision and image processing, including edge detection in laser range finder data, convolution, a local contrast enhancement algorithm, and two-dimensional fast Fourier transforms. We are currently benchmarking these and other algorithms for the purpose of comparison with alternate technologies.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratories.

4.49

NEURAL NETWORK MODELING OF EARLY RETINAL VISION PROCESSES

C. C. Jorgensen

(Abstract of paper presented at NEUROCOM I, San Jose, CA, July 27-30, 1986)

This paper considers two techniques to obtain values for parameters in models of vision processes in early layers of the human retina. The work is part of a long-term effort to develop a robot vision system using three computational principles of neural networks. These principles are: massive parallelism, dynamic feedback, and multi-layer pattern recognition. Two network models were studied. The first represented lateral inhibition processes as a matrix of two-dimensional linear equations with limited feedback. The second represented multi-layer networks as matrices of dynamic, two-dimensional nonlinear differential equations. The lateral inhibition model was parameterized using psychophysical data from human judgments of pattern brightness in a machband illusion. A 2-D Fourier transform was made of original and perceived patterns and used to solve for the coefficient matrix of the neural network. The coefficients were then applied to the pixel matrix of a Herman grid illusion and compared with the corresponding human subjective results through three-dimensional plots of pixel intensities. The second model was analyzed using a new computer simulation developed to work with moving images and adjustable neural connection topologies.

Research sponsored by U.S. Army Human Engineering Laboratory.

4.50

MODELLING EARLY STAGES OF HUMAN VISION

C. C. Jorgensen R. Gawronski*
F. Holly[†]

(Abstract of ORNL/TM-10031, August 1986)

This report presents the first results of an effort to model vision processes operating in the early layers of the human retina. The ultimate goal of this research is to develop a robot vision system based on computational principles of human vision. These include massive parallelism, dynamic feedback, and multilayer pattern recognition. Two neural models were developed. The first represented early vision in terms of static two-dimensional linear equations using a linear matrix and limited feedback. The second considered dynamic two-dimensional nonlinear processes and used matrices of nonlinear differential equations. The first set of equations was parameterized using psychophysical data from subjective intensity judgments for visual illusions. Illusions were quantified by creating a digitized image representing the subjective effect of human perception when exposed to input patterns. A Fourier transform was made of the input and output patterns and used to solve for the coefficients of the retinal operator equations. The equations were then applied to new illusions and compared with human subjective results through three-dimensional plots of output pixel intensities. The second model with dynamic equations was studied using a computer simulation developed to operate on varying input wave forms and variable neural connection topologies.

Research sponsored by U.S. Army Human Engineering Laboratory, U.S. DOE Office of Basic Energy Sciences.

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[†]U.S. Army Engineering Laboratory, Aberdeen Proving Grounds, MD.

4.51

MULTI-SENSOR INTEGRATION USING CONCURRENT COMPUTING

R. C. Mann

(Abstract of paper presented at the SPIE Symposium on Infrared Sensors and Sensor Fusion, Orlando, FL, May 18-22, 1987)

This paper addresses methods for high and low level multi-sensor integration based on maintaining consistent labelings of features detected in different sensor domains. Implementation in a concurrent computing environment is discussed. Research sponsored by U.S. DOE Office of Basic Energy Science and Office of Technology Support Programs.

4.52

MULTI-SENSOR INTEGRATION FOR A MOBILE ROBOT USING CONCURRENT COMPUTING

R. C. Mann

(Abstract of paper presented at the Advanced Robotics Program Workshop on Manipulators, Sensors, and Steps Towards Mobility, Nuclear Research Center, Karlsruhe, Federal Republic of Germany, May 11-13, 1987)

The subject of this paper is the integration of pieces of information from multiple sensors on a mobile robot system (HERMIES) which is under development at the Center for Engineering Systems Advanced Research (CESAR) at Oak Ridge National Laboratory (ORNL). CESAR was established in 1983 as a center for multi-disciplinary, long-range research and development in machine intelligence and advanced control theory.

Any advanced robot system, teleoperated or autonomous, must rely on data and information supplied by several, often partly redundant, sensors that either actively or passively probe the environment. Multi-sensor integration (MSI), also referred to as sensor fusion, has become an increasingly active area of research and development during the past few years. Results obtained with integrating information from vision and sonar sensors will be presented to illustrate some of the features of the MSI approach.

Research sponsored by Engineering Research Program, U.S. DOE Office of Basic Energy Sciences

4.53

ANALYSIS OF TWO-DIMENSIONAL PROTEIN PATTERNS USING THE NCUBE HYPERCUBE

R. C. Mann

[Abstract of oral presentation given at the Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986 (full paper not submitted for proceedings)]

Processing and quantitative analysis of digital images are important areas of application for multiprocessors. This article describes an application of an NCUBE hypercube to a complex problem in biomedical image analysis: the quantitative analysis of images generated by two-dimensional gel electrophoresis. This is a method to separate proteins according to their molecular weights and mobilities in an electric field at a certain pH value. The presence of a radioactively or fluorescently labeled protein in a preparation is indicated by a spot that is produced on a film with the intensity of the spot indicative of the amount of protein. There are hundreds, possibly thousands of proteins commonly present in a preparation, which makes rigorous quantitative analysis by simple visual inspection impossible. A system to perform this analysis was developed recently at ORNL on a serial minicomputer with a commercially available pipelined image processor.

Implementation on a 64-node NCUBE hypercube of a nonlinear filter used for elimination of spatially varying gel image background resulted in an increase in processing speed by 1-2 orders of magnitude compared to the original system and by a factor of almost two compared to the ORNL Cray XMP-12. Methods of computational geometry are being considered for comparison of spot patterns resulting from gel images. The goal is to detect differences as well as similarities between patterns that are produced by spatial distortions and/or deletions and insertions of spots. The hypercube appears to be an appropriate, flexible tool for the study of nonlinear filters in image processing and analysis, as well as for dealing with the high complexity of problems involved in image comparison.

Research sponsored by U.S. DOE Office of Health and Environmental Research and Office of Basic Energy Sciences.

4.54

QUANTITATIVE ANALYSIS OF TWO-DIMENSIONAL PROTEIN PATTERNS USING AN NCUBE HYPERCUBE

R. C. Mann

(Abstract of paper presented at the Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986)

This paper presents preliminary results obtained at ORNL with a 64-node hypercube applied to the quantitative analysis and comparison of images generated by two-dimensional electrophoresis. The applicability of methods that were developed in the course of this work is not confined to images of this type. The algorithms include nonlinear "morphological" filters for the removal of spatially varying image background. For this set of operations, processing time could be decreased by 1-2 orders of magnitude compared to a sequential minicomputer, and by a factor of almost two compared to a Cray XMP-12. In addition to parallelizing gel image processing and analysis algorithms for the hypercube in order to increase processing speed, novel approaches to the reliable detection of differences and similarities between gel images are being investigated with the hypercube. These include matching of graphs defined by the spot patterns extracted from gel images, and the knowledge-based analysis of sequences of images in an experiment. The hypercube appears to be an appropriate, flexible tool for the investigation of nonlinear filters for image processing and analysis, as well as for handling the high complexity of problems involved in image comparison.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratories.

4.55

STOCHASTIC RELAXATION FOR DIGITAL IMAGE PROCESSING USING A HYPERCUBE ARCHITECTURE

R. C. Mamm G. L. Bilbro*

(Abstract of paper to be presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

During the past four years the use of iterative techniques for image processing and analysis based on statistical image models has been receiving increasing attention. This is mostly a consequence of recent publications of methods for the approximate solution of combinatorial optimization problems, e.g., simulated annealing, and of the increasing availability of concurrent computers to execute these computationally very expensive algorithms. In stochastic relaxation (SR) an analogy is made between the values that a picture element (pixel) can take on in an image and the states of atoms in a physical system defined on a rectangular lattice. The energy function of the fictitious physical system defines its Gibbs distribution. Since the distribution of a Markov random field (MRF) is Gibbs, the energy function also determines a MRF image model. It can be shown that for many image degradations the posterior distribution of the image given the data is also Gibbs. Therefore, minimizing the energy associated with that distribution is equivalent to maximum *a posteriori* (MAP) estimation of the image from the corrupted data.

The hypercube concurrent processor proves to be a valuable tool for the study of computationally expensive methods in image processing and analysis, such as SR algorithms.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Technology Support Programs.

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4.56

CONCURRENT ALGORITHMS FOR A MOBILE ROBOT VISION SYSTEM

R. C. Mamm J. P. Jones

(Abstract of paper to be presented at the Applications of Artificial Intelligence Conference, Orlando, FL, April 4-8, 1988)

This paper describes the integration of robot vision algorithms on a 4-dimensional hypercube system on board a mobile robot developed at Oak Ridge National Laboratory. The integrated system is interfaced to the navigation and robot control software, enabling the robot to maneuver in a laboratory environment containing non-stationary obstacles, to find a known object of interest and to recognize the object's status based on visual sensing.

The system uses two calibrated cameras with different focal length lenses. Distance information is inferred from *a priori* knowledge of relative sizes of certain objects in the environment. Images are digitized using Datacube hardware (Datacube, Inc., Peabody, MA) mounted in a VME system on board the robot. Signal processing and scene analysis are performed on an on-board NCUBE-AT system that is interfaced to the VME bus. Among the procedures to be described in detail in this paper are a new component labeling algorithm and a Hough transform algorithm with load balancing that are optimally adapted to the hypercube architecture. This system analyzes a scene in less than 5 seconds and proves to be a valuable experimental tool for research in mobile autonomous robots.

Research sponsored by U.S. DOE Office of Technology Support Programs and Office of Basic Energy Sciences.

4.57

A COMPARISON OF ALGORITHMS FOR THE ANALYSIS OF IMAGES GENERATED BY TWO-DIMENSIONAL ELECTROPHORESIS

R. C. Mann D. J. Riese*
B. K. Mansfield† J. K. Selkirk‡

[Abstract of ORNL/TM-10591, November 1987; also *Electrophoresis* (in press)]

Three algorithms for quantitative 2d gel electrophoresis were compared when applied to a set of simulated images and to gel images obtained with separated cytoplasmic proteins of FELC. The methods involved fitting of Gaussian surfaces to protein spots as well as quantitation that did not rely on any assumptions concerning the distribution of radioactivity within a protein spot. Image processing algorithms preceding the analysis were identical for the three methods. Results based on isolated spots show that for the majority of cases there is no statistical difference between the estimates produced by the three methods. This suggests that computationally expensive fitting of two-dimensional surfaces is not necessary in order to achieve satisfactory quantitation.

Research sponsored by U.S. DOE Office of Health and Environmental Research.

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‡National Toxicology Program, Research Triangle Park, NC.

4.58

EXPRESSION OF CYTOPLASMIC PROTEINS IN FRIEND ERYTHROLEUKEMIA CELLS CHEMICALLY-INDUCED TO UNDERGO TERMINAL ERYTHROID DIFFERENTIATION

B. K. Mansfield† J. K. Selkirk†
R. C. Mann

(Abstract of paper presented at the Annual Conference of the American Association for Cancer Research, Atlanta, GA, May 20-23, 1987)

It can be postulated that variation in enzymatic processing of chemical carcinogens contri-

butes to the wide range in susceptibility and resistance of different cell types to chemical carcinogenesis. A two-dimensional gel electrophoresis (2-DGE) and data analysis system has been assembled to ascertain cellular protein differences in response to carcinogen insult. The biochemically well-characterized Friend Erythroleukemia Cell (FELC) line undergoing a program of erythroid differentiation was utilized as the initial biological system in this research to test protocols for facile image comparison and to determine the ability of this analytical system to demonstrate qualitative and quantitative protein modulations in response to chemical treatment. Protocols were developed for merging replicate qualitative treatment and control 2-DGE data into a single data file for display and easy visualization of treatment and control polypeptide profiles in one plane. A rationale for comparing quantitative data values (derived from averaged replicates) was developed so that relative synthesis rates could be compared between corresponding spots in FELC which have been induced to undergo a program of erythroid differentiation with hexamethylene-bisacetamide (HMBAA) and untreated FELC. A total of 97 polypeptides were demonstrated by this 2-DGE and data analysis system to be induced or repressed during the program of terminal differentiation in FELC. Five polypeptides were shown to vary quantitatively from the corresponding control spots. This 2-DGE and analysis system is capable of demonstrating both quantitative and qualitative protein perturbations in cells undergoing chemical treatment.

Research sponsored by NIEHS, Research Triangle Park, NC.

*Biology Division.

†National Toxicology Program, Research Triangle Park, NC.

World Modeling

4.59

3-D WORLD MODELING BASED ON COMBINATORIAL GEOMETRY FOR AUTONOMOUS ROBOT NAVIGATION

M. Goldstein* F. G. Pin
G. de Saussure C. R. Weisbin

[Abstract of paper presented at the 1987 IEEE International Conference on Robotics and Automation, Raleigh, NC, March 30 — April 3, 1987; Proc. Vol. 2, p. 727 (1987)]

In applications of robotics to surveillance and mapping at nuclear facilities, the scene to be described is three-dimensional. Using range data, a 3-D model of the environment can be built. First, each measured point on the object surface is surrounded by a solid sphere with a radius determined by the range to that point. Then, the 3-D shapes of the visible surfaces are obtained by taking the (Boolean) union of the spheres. Using this representation, distances to boundary surfaces can be efficiently calculated. This feature is particularly useful for navigation purposes. The efficiency of the proposed approach is illustrated by a simulation of a spherical robot navigating in a 3-D room with static obstacles.

Research sponsored by U.S. DOE Office of Basic Energy Sciences/Engineering Research Program and Office of Facilities, Fuel Cycle, and Test Program.

*Nuclear Research Center-Negev, Israel.

4.60

3-D WORLD MODELING WITH UPDATING CAPABILITY BASED ON COMBINATORIAL GEOMETRY

M. Goldstein* F. G. Pin
G. de Saussure C. R. Weisbin

(Abstract of paper presented at a Workshop on Space Telerobotics, California Institute of Technology, Pasadena, CA, January 20-23, 1987)

This paper describes a 3-D world modeling technique using range data. Range data quantify

the distances from the sensor focal plane to the object surface, i.e., the 3-D coordinates of discrete points on the object surface are known. The approach proposed herein for 3-D world modeling is based on the Combinatorial Geometry (CG) Method which is widely used in Monte Carlo particle transport calculations. First, each measured point on the object surface is surrounded by a small sphere with a radius determined by the range to that point. Then, the 3-D shapes of the visible surfaces are obtained by taking the (Boolean) union of all the spheres. The result is an unambiguous representation of the object's boundary surfaces. The "pre-learned" partial knowledge of the environment can be also represented using the CG Method with a relatively small amount of data. Using the CG type of representation, distances in desired directions to boundary continuously verifying the world model against the data provided by a range finder, and for integrating range data from successive locations of the robot during motion. The efficiency of the proposed approach is illustrated by simulations of a spherical robot in a 3-D room in the presence of moving obstacles and inadequate pre-learned partial knowledge of the environment.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Nuclear Research Center-Negev, Israel.

4.61

3-D WORLD MODELING WITH OBJECT RECOGNITION FOR A MOBILE ROBOT

M. Goldstein* F. G. Pin
C. R. Weisbin

(Abstract of paper to be presented at a Workshop on Spatial Reasoning and Multi-Sensor Fusion, St. Charles, IL, October 5-7, 1987)

This paper describes a 3-D world modeling technique using range data. Range data quantify the distances from the sensor focal plane to the object surface, i.e., the 3-D coordinates of discrete points on the object's surface are known.

The proposed approach is based on the Combinatorial Geometry Method which is widely used in Monte Carlo particle transport calculations. For the construction of the 3-D model, each measured point on the object surface is surrounded by a small sphere with a radius determined by the range to that point. Then, the approximate 3-D shapes of the visible surfaces are obtained by taking the (Boolean) union of all the spheres. The result is an unambiguous representation of the objects' boundary surfaces. The "pre-learned" partial knowledge of the environment can also be represented using the Combinatorial Geometry method with a relatively small amount of data. Using the combinatorial geometry type of representation, distances in desired directions to boundary surfaces of various objects are efficiently calculated. This feature is particularly useful for continuously verifying the world model against the data provided by a range finder, and for integrating range data from successive locations of the robot during motion. The methodology also includes a segmentation and object recognition procedure which allows very efficient storage of geometric information. The process of segmentation starts with merging pixels with similar ranges (less than a specified threshold) in the first range image. The resulting "patches" are given unique label numbers. The pixels in the subsequent range images are merged and labeled using a continuous procedure if some of the new pixels belong to previously labeled patches, or a discrete procedure otherwise. The output of the segmentation process consists of patches or "objects" that are identified by a unique label number. Subsequently, the external boundary surface of each object is partitioned into "surface patches" which are classified as planar, convex or concave. The prominent pixels characterizing each surface patch are then extracted and a graph structure is constructed for each object in the scene. These graph structures are matched against those of objects stored in a database. Each object in the database is represented by a graph structure and by its Combinatorial Geometry description. After recognition of an object has taken place the previous surface representation is replaced with the more concise

Combinatorial Geometry volumetric representation of the object. Several simulations of a volumetric robot navigating in a 3-D room with moving obstacles and inadequate pre-learned partial knowledge of the environment are presented to illustrate the efficiency of the proposed procedure. The applicability of the methodology to the more general problem of scene description using coupling with information provided by other sensors is also discussed.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

* Nuclear Research Center-Negev, Israel.

4.62

3-D WORLD MODELING FOR AN AUTONOMOUS ROBOT

M. Goldstein* F. G. Pin
C. R. Weisbin

(Abstract of paper to be presented at the 1987 SPIE Cambridge Symposium on Advances in Intelligent Robot Systems, Cambridge, MA, November 1-4, 1987; also paper entitled "Range Image Segmentation and Surface Parameter Extraction for a Mobile Robot" to be presented at the 1988 IEEE International Conference on Robotics and Automation, Philadelphia, PA, April 25-29, 1988)

This paper presents a methodology for a concise representation of the 3-D world model for a mobile robot using range data. The process starts with the segmentation of the scene into "objects" that are given a unique label, based on principles of range continuity. Then the external surface of each object is partitioned into homogeneous surface patches. Contours of surface patches in 3-D space are identified by estimating the normal and curvature associated with each pixel. The resulting surface patches are then classified as planar, convex or concave. Since the world model uses a volumetric representation for the 3-D environment, planar surfaces are represented by thin volumetric polyhedra. Spherical and cylindrical surfaces are extracted and represented by appropriate volumetric primitives. All other surfaces are represented using the boolean union of spherical volumes (as described in a separate paper by the same authors). The result is a general, concise representation of the external 3-D

world, which allows for efficient and robust 3-D object recognition.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Nuclear Research Center-Negev, Israel.

4.63

3-D WORLD MODELING FOR A MOBILE ROBOT

M. Goldstein* F. G. Pin
C. R. Weisbin

(Abstract of paper presented at the 1987 Goddard Conference on Space Applications of Artificial Intelligence and Robotics, Greenbelt, MD, May 13-14, 1987)

This paper describes a 3-D world modeling technique using range data. Range data quantify

the distances from the sensor focal plane to the object surface, i.e., the 3-D coordinates of discrete points on the objects' surface are known. The approach proposed herein for 3-D world modeling is based on the Combinatorial Geometry Method which is widely used in Monte Carlo particle transport calculations. The efficiency of the proposed methodology is illustrated in several simulations of a volumetric robot navigating in a 3-D room with moving obstacles and inadequate prelearned partial knowledge of the environment.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Spent Fuel Management and Reprocessing.

*Nuclear Research Center-Negev, Israel.

Man-Machine Symbiosis

4.64

ANALYSIS OF TASKS FOR DYNAMIC MAN/MACHINE LOAD BALANCING IN ADVANCED HELICOPTERS

C. C. Jorgensen

(Abstract of ORNL/TM-10558, October 1987)

This report considers task allocation requirements imposed by advanced helicopter designs incorporating mixes of human pilots and intelligent machines. Specifically, it develops an analogy between load balancing using distributed non-homogeneous multiprocessors and human team functions. A taxonomy is presented which can be used to identify task combinations likely to cause overload for dynamic scheduling and process allocation mechanisms. Designer criteria are given for function decomposition, separation of control from data, and communication handling for dynamic tasks. Possible effects of n -p complete scheduling problems are noted and a class of combinatorial optimization methods are examined.

Research sponsored by AAAI Program Office of NASA Ames Research Center, Moffet Field, CA.

4.65

A METHODOLOGY FOR DYNAMIC TASK ALLOCATION IN A MAN-MACHINE SYSTEM

L. E. Parker F. G. Pin

(Abstract of paper to be presented at the Second International Symposium on Methodologies for Intelligent Systems, Charlotte, NC, October 14-17, 1987)

This paper presents a methodological approach to the dynamic allocation of tasks in a man-machine symbiotic system in the context of dexterous manipulation and teleoperation. This paper addresses symbiosis containing two symbiotic partners which work toward controlling a single manipulator arm for the execution of a series of sequential manipulation tasks. The proposed automated task allocator uses knowledge about the allocation policies of the problem, the available resources, and the tasks to be performed to dynamically allocate tasks to the man and the machine.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.66

DYNAMIC TASK ALLOCATION FOR A MAN-MACHINE SYMBIOTIC SYSTEM

L. E. Parker F. G. Pin

(Abstract of ORNL/TM-10397, June 1987; also paper presented at the 1987 Goddard Conference on Space Applications of Artificial Intelligence and Robotics, Greenbelt, MD, May 13-14, 1987)

This report presents a methodological approach to the dynamic allocation of tasks in a man-machine symbiotic system in the context of dexterous manipulation and teleoperation. This report addresses a symbiotic system containing two symbiotic partners which work toward controlling a single manipulator arm for the execution of a series of sequential manipulation tasks. It is proposed that an automated task allocator use knowledge about the constraints/criteria of the problem, the available resources, the tasks to be performed, and the environment to dynamically allocate task recommendations for the man and the machine. The presentation of the methodology includes discussions concerning the interaction of the knowledge areas, the flow of control, the necessary communication links, and the replanning of the task allocation. Examples of task allocation are presented to illustrate the results of this methodology.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.67

ARCHITECTURE FOR DYNAMIC TASK ALLOCATION IN A MAN-ROBOT SYMBIOTIC SYSTEM

L. E. Parker F. G. Pin

(Abstract of paper to be presented at 1987 SPIE Cambridge Symposium on Advances in Intelligent Robot Systems, Cambridge, MA, November 1-6, 1987)

Recent research in telerobotics and artificial intelligence has recognized the need for an integration of autonomous intelligent robot technology with developments in advanced teleoperation and servomanipulation to create a new class of automated system referred to as "Man-Robot Symbiosis." The ultimate function of such symbiotic systems is to dynamically optimize the division of work between the man and the robot and to facilitate their cooperation through shared knowledge, skills, and experience. This paper presents a methodological approach to the dynamic allocation of tasks for a man-robot symbiotic system in the context of dextrous manipulation and teleoperation. The proposed architecture is shown to allow dynamic task reallocation due to changes in the work constraints and physical environment, as well as to unanticipated events and human requests or controls. In this paper, two symbiotic partners are considered, a human teleoperator and an intelligent robotic system, which work toward controlling a single manipulator arm for the execution of a series of sequential manipulation tasks. The role of the dynamic task allocator within the overall symbiotic system and its interaction with other essential components of the system is discussed. The knowledge necessary to perform the allocation of tasks to the man and the robot, along with the flow of execution is then presented. An example is given to illustrate the results of the task allocation implementation.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

Uncertainty Analysis

4.68

CONCEPTS INVOLVED IN A PROPOSED APPLICATION OF UNCERTAINTY ANALYSIS TO THE PERFORMANCE ASSESSMENT OF HIGH-LEVEL NUCLEAR WASTE ISOLATION SYSTEMS

R. E. Maerker

(Abstract of ORNL/TM-9955, March 1986)

This report introduces the concepts of a previously developed methodology which could readily be extended to the field of performance assessment for high-level nuclear waste isolation systems. The methodology incorporates sensitivities previously obtained with the GRESS code into an uncertainty analysis, from which propagated uncertainties in calculated responses may be derived from basic data uncertainties. Following a definition of terms, examples are provided illustrating commonly used conventions for describing the concepts of covariance and sensitivity. Examples of solutions to problems previously encountered in related fields involving uncertainty analysis and use of a generalized linear least-squares adjustment procedure are also presented.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

4.69

FOUNDATIONS OF O-THEORY II: MEASUREMENTS AND RELATION TO FUZZY SET THEORY

E. M. Oblow

(Abstract of ORNL/TM-10493, July 1987)

A conceptual experiment framework for O-theory and the possibility form of fuzzy set theory is presented. The framework is probabilistic and derived from experimental measurements of evidential support. It is used to quantify the probabilistic masses needed in O-theory and the membership functions used in fuzzy set theory. Instances in which these two different representations of the same experimental data are

equivalent are then explored. The relationships between general operators in both theories are then discussed, along with their connection to Dempster-Shafer theory. Finally, several illustrative examples of deductive inferencing under uncertainty are solved. The equivalence of the representations of the results in both uncertainty theories is demonstrated.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.70

O-THEORY: A PROBABILISTIC ALTERNATIVE TO FUZZY SET THEORY

E. M. Oblow

[Abstract of chapter in *Lecture Notes in Computer Science*, Volume title "Uncertainty in Knowledge-Based Systems," Yager and Bouchon, Eds. (in press)]

A hybrid uncertainty theory is developed to bridge the gap between fuzzy set theory and Dempster-Shafer theory. Its basis is the Dempster-Shafer formalism, which is extended to include a complete set of basic operations for handling uncertainties in a set-theoretic framework. The new operator theory, O-Theory, retains the probabilistic flavor of Dempster's original point-to-set mappings but includes the potential for defining a range of operators like those found in fuzzy set theory.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.71

FOUNDATIONS OF O-THEORY I: THE INTERSECTION RULE

E. M. Oblow

(Abstract of ORNL/TM-9983, March 1986)

In a previous paper, O-theory (OT), a hybrid uncertainty theory was proposed for dealing with problems of uncertainty in logical inference. The foundations of one of the concepts introduced, the

OT intersection operator, are explored in this paper. The developments rely solely on set-theoretic and probability theory notions.

The original OT intersection rule had as its basis Dempsters' rule of combination. A more fundamental basis for the OT rule will be shown to be classical probability theory. Mass assignments in the Dempster-Shafer theory (DST) formalism are first reevaluated yielding a more basic relationship between masses and probabilities. These results are then used to show that the OT intersection rule can be derived from first principles in probability theory. Furthermore, without resort to conditional probabilities, a simpler axiomatic basis can be used to establish this rule. It can, therefore, be used as alternative to Bayes' theorem for combining probabilistic belief consistently. Dempsters' rule will be shown to be a special case of the OT result. It too will be derived from probability theory axioms.

The formal connection between mass and probability presented also makes distinctions between DST and probability theory less consequential. DST is still seen to be a generalization of the concept of probability, but it now fits within the original probability framework. The DST conception of uncommitted belief will also be shown to be compatible with probability theory.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.72

EXTENSION OF O-THEORY TO PROBLEMS OF LOGICAL INFERENCE

E. M. Oblow

[Abstract of ORNL/TM-10107, March 1987; also *Int. J. Intelligent Systems* (in press)]

This paper extends Operator-Uncertainty Theory (OT) to the problem of uncertainty propagation in logical inferencing systems. The OT algebra and propositional interpretations presented in previous papers are applied here to derive operators for logical inferencing in the presence of conflict and undecidability. Operators for propagating uncertainties through the

logical operations of disjunction and conjunction are defined. In addition, new OT operators for implication, modus ponens and modus tollens are also proposed.

The operators derived using the OT methodology are found to give rise to a four-valued logic similar to that used in computer circuit design. This framework allows uncertainty in inferencing to be represented in the form of rules convenient for use in expert systems as well as logical networks. The theory is general enough to deal with questions of conflict and undecidability and to propagate their effects through the most widely used inference operations.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.73

O-THEORY — A HYBRID UNCERTAINTY THEORY

E. M. Oblow

[Abstract of ORNL/TM-9759, October 1985; also *Int. J. Gen. Sys.* 13, 95 (1987); also paper in the *Proc. International Conference on Information Processing and Management of Uncertainty on Knowledge-Based Systems*, p. 231, Paris, France, 1986]

A hybrid uncertainty theory is developed to bridge the gap between fuzzy set theory and Bayesian inference theory. Its basis is the Dempster-Shafer formalism (a probability-like, set-theoretic approach), which is extended and expanded upon so as to include a complete set of basic operations for manipulating uncertainties in approximate reasoning. The new theory, operator-belief theory (OT), retains the probabilistic flavor of Bayesian inference but includes the potential for defining a wider range of operators like those found in fuzzy set theory.

The basic operations defined for OT in this paper include those for: dominance and order, union, intersection, complement and general mappings. A formal relationship between the membership function in fuzzy set theory and the upper probability function in the Dempster-Shafer formalism is also developed. Several sample problems in logical inference are worked out

to illustrate the results derived from this new approach as well as to compare them with the other theories currently being used. A general method of extending the theory using the historical development of fuzzy set theory as an example is suggested.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.74

A HYBRID DETERMINISTIC PROCEDURE FOR AUTOMATED SENSITIVITY AND UNCERTAINTY ANALYSIS

F. G. Pin B. A. Worley
R. E. Maerker E. M. Obrow

(Abstract of paper presented at the American Nuclear Society International Topical Meeting on Waste Management and Decontamination and Decommissioning, Niagara Falls, NY, September 14-18, 1986)

A deterministic procedure for automating sensitivity and uncertainty analysis for large-scale studies is presented. The procedure makes use of the GRESS (GRAdient Enhanced Software System) methodology to calculate the required sensitivities. GRESS is a precompiler that automatically enhances computer codes with computer calculus in such a way that partial derivatives can be calculated along with the normal results of the code. From these derivatives any sensitivity of interest can readily be obtained. The sensitivities can then be used in an uncertainty analysis procedure based on the quantification of covariances and parameter correlations, in conjunction with conventional statistical uncertainty methods. When this approach is used, the procedure may also include the use of a generalized least-square adjustment methodology for reducing the uncertainties in the final results by combining calculated or measured integral experiment data with the data used in the calculations.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

4.75

DETERMINISTIC UNCERTAINTY ANALYSIS

B. A. Worley

[Abstract of ORNL-6428 (in press); also *Trans. Am. Nucl. Soc.* 55, 312 (1987)]

Uncertainties of computer results are of primary interest in applications such as high-level waste repository performance assessment in which experimental validation is not possible or practical. Because of the complex computational structure of large computer models and because of the large number of input and data parameters associated with such models, to date almost all uncertainty analysis of computer results has been performed using a statistical approach. This paper presents a deterministic uncertainty analysis (DUA) method for calculating uncertainties that has the potential to significantly reduce the number of computer runs required for conventional statistical analysis. The method is based upon the availability of derivative and sensitivity data such as that calculated using the well known direct or adjoint sensitivity analysis techniques. Formation of response surfaces using derivative data and the propagation of input probability distributions are discussed relative to their role in the DUA method. A sample problem that models the flow of water through a borehole is used as a basis to compare the cumulative distribution function of the flow rate as calculated by the standard statistical methods and the DUA method. Propagation of uncertainties by the DUA method is compared for ten cases in which the number of reference model runs was varied from one to ten. The DUA method gives a more accurate representation of the true cumulative distribution of the flow rate based upon as few as two model executions compared to fifty model executions using a statistical approach.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

Energy-Economy Modeling

4.76

A COMPARISON STUDY OF THE RAMSGAS MODEL AND THE NATIONAL ENERGY POLICY PLAN PROJECTIONS TO 2010

E. A. Browne* D. B. Reister
L. D. Trowbridge

(Abstract of ORNL/TM-10159, November 1986)

This report documents the results of a validation exercise comparing the RAMS World Natural Gas Model to the National Energy Policy Plan Projections to 2010. The purposes of this study are twofold: (1) determine the changes necessary to RAMSGAS input parameters to duplicate NEPP-85 results; and (2) test the flexibility and robustness of the RAMSGAS model by demonstrating its capability to produce results higher than the NEPP-85 high growth case, and lower than the NEPP-85 low growth case. Four scenarios were developed for the study: a reference scenario, NEPP-match scenario, and high and low growth scenarios. The changes made to RAMSGAS in this study were to the numerical values of the parameters only; no equations were altered. Comparisons were made between projections of world oil and natural gas prices and production through 2010.

The results of this study show that RAMSGAS is easily capable of duplicating the long-term trends of the NEPP-85 study. Short term behavior could only be duplicated by large adjustments to RAMSGAS parameters, and not all parameters could be exactly matched.

Research sponsored by U.S. DOE Office of Advanced Fuels, Technology, Extraction, and Environmental Controls.

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4.77

THE RESEARCH AND DEVELOPMENT ANALYSIS MODELING SYSTEM WORLD NATURAL GAS MODEL (RAMSGAS) FINAL DOCUMENTATION

E. A. Browne* D. B. Reister
L. D. Trowbridge J. V. Conopask†
E. Hicks† P. Muhlmeister†

(Abstract of ORNL/TM-10157, December 1986; also paper entitled "RAMSGAS: A Micro-Computer-Based World Gas Market Model" by E. Hicks, J. V. Conopask, P. Muhlmeister, D. B. Reister, L. D. Trowbridge, and F. G. Pin in Proc. of the 14th Energy Technology Conference and Exposition, Washington, DC, April 14-16, 1987 (in press))

The Research and Development Analysis Modeling System World Natural Gas Model (RAMSGAS) was developed for the U.S. Department of Energy, Office of Advanced Fuels, Technology, Extraction, and Environment Controls to support planning of unconventional gaseous fuels R&D. The DOE decided that a framework was needed that would allow analysts to easily vary assumptions about future world natural gas markets. The model is a scenario analysis tool constructed for IBM PC compatible micro-computers. The model structure is based on a traditional supply/demand framework, and also accounts for the non-renewable nature of gas resources. The model estimates consumption, production, and prices in each region every five years for conventional and unconventional natural gas and oil. Demand for oil and gas is determined by energy growth rates and price-induced conservation for each of the nine demand regions which partition the world. Once demand estimates are established in each region, a share of that demand is allocated to natural gas, depending on the average gas price relative to projected oil prices. Gas is supplied by 11 conventional and 19 unconventional sources, and market shares are determined according to relative delivered prices. Scenarios can be changed, saved, and retrieved easily and the results accessed through automatic printing and graphics routines.

Research sponsored by U.S. DOE Office of Advanced Fuels, Technology, Extraction, and Environmental Controls.

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4.78

REPLACEMENT COST INTEGRATION PROGRAM (RESERVE REPLACEMENT VERSION) USER'S GUIDE

J. R. Einstein L. D. Trowbridge

(Abstract of ORNL/TM-10143, September 1986)

RCIP, the Replacement Cost Integration Program, was developed for the Department of Energy's Office of Planning and Environment within the Office of Fossil Energy. It is a PC-based tool designed to aid the study of the replacement of domestic oil reserves by new discoveries. Its function is primarily to translate regional supply functions (replacement cost/quantity functions) for undiscovered oil into a projection of future reserve additions.

The primary data input to RCIP takes the form of undiscovered resource bases broken down by region and production cost. Other assumptions address demand for domestic oil, resource availability as a function of time (leasing and technology constraints), and availability of enhanced oil recovery (EOR) production. A series of menus allows the user to control many of these data elements to create a wide range of scenarios of future oil discoveries. Projections of reserve additions are made by selecting demanded quantities by a series of simplified priority schemes, the most important of which is that the least costly resources will be discovered first.

The user's guide for RCIP contains detailed directions for operation of the RCIP system of programs, as well as a description of the program logic, assumptions, and data sources.

Research sponsored by U.S. DOE Office of Planning and Environment.

4.79

A COMPACT MODEL OF OIL SUPPLY DISRUPTIONS

D. B. Reister

[Abstract of ORNL/TM-10519, August 1987; also *Resources and Energy J.* (in press)]

We have developed a model of oil price jumps caused by oil supply disruptions. The core of the model is a compact general equilibrium model of oil demand. Given an exogenous forecast of oil supply and potential GNP for the world, the model can forecast the oil price, real GNP, and Value Added for the world.

The data base for the model consists of historical time series of world oil supply, world oil price, and growth rates for world GNP. The data demonstrate that small changes in oil supply are associated with large changes in oil price. If a large change in oil price causes a small change in oil consumption, the short-run price elasticity of demand must be small. We have specified a model with a short-run and a long-run price elasticity. The six parameters in the model have been estimated using historical data for three cases. The initial model had five parameters. For Case I, we used a search procedure to determine the parameters that minimized the root mean square (RMS) of the differences between the price backcast by the model and the historical data on oil price. We found that the RMS error was 121% and that the price calculated by the model was too low for the period from 1974 to 1980. After a review of the historical data on oil consumption, oil price, and world GNP, we concluded that the response of the world oil market to the 1974 oil price shock was different than the response to the 1979-80 oil price shock. After the jump in oil price from 1973 to 1974, the consumption of oil decreased in 1975 but quickly recovered and reached a peak in 1979. After the jump in oil price from 1978 to 1980, the consumption of oil declined steadily for four consecutive years. To improve the model's capacity to simulate the historical data, we introduced a technological change factor that increases the demand for oil in the period from 1971 to 1979.

For Case 2, the rate of technological change is 3.8% and the RMS error is 35%. For Case 3, the rate of technological change is 7.0% and the RMS error is 35%. Although Case 3 has the smallest error, we concluded that the Case 2 set of parameters provided the best match for the historical data on world oil price. For Case 2, we find a small short-run elasticity (-0.09), a substantial long-run elasticity (-0.92), and a lag of 0.08, which corresponds to 12 years. We have invented an oil price scenario that is similar to the historical data and have determined the corresponding oil supply scenario for the Case 2 set of parameters.

Research sponsored by U.S. DOE-Fossil Energy Office of Planning and Environment.

4.80

VALIDATING ALLOCATION FUNCTIONS IN ENERGY MODELS: A COMMENT

D. B. Reister

[Abstract of *The Energy Journal* 8(1), 151 (1987)]

In their recent paper, Smith and Hill (1985) perform a numerical experiment to compare three allocation functions: translog, logistic, and probabilistic. They found that the logistic function was generally better than the other two alternatives and that the probabilistic function was distinctly inferior to other methods in nearly all experiments. They observe that the probabilistic function has wide application in energy models and hope that their paper may dampen the enthusiasm for the probabilistic function.

Unfortunately, Smith and Hill have descended from science to rhetoric; they have established a straw man and demolished it. Their probabilistic function is a special case of the logistic function; it has a zero value for the constant term and a fixed value (8.0) for the exponent. No one should be surprised that functions with parameters chosen to match a data set should have smaller errors than a function with no degrees of freedom.

Research sponsored by U.S. DOE Office of Fossil Energy.

4.81

THE LINK BETWEEN ENERGY AND GDP IN DEVELOPING COUNTRIES

D. B. Reister

[Abstract of *Energy* 12(6), 427 (1987); also *ASSET* (in press)]

Historical studies of the energy demand patterns of the industrial countries show increasing energy intensity followed by decreasing intensity. To explore the energy intensity patterns of developing countries, a data base was assembled for 38 developing countries. The data base contains estimates of per capita energy demand and gross domestic product (GDP) for 1950, 1960, 1970, and 1980. If the GDP is measured using the purchasing power parity method, analysis of the data base demonstrates an increase in energy intensity as countries develop.

Research sponsored by U.S. DOE Office of Planning and Environment.

4.82

FUTURE DEMAND FOR FUEL AND ELECTRICITY

D. B. Reister

[Abstract of *Resources and Energy* 9, 121 (1987); also paper presented at the Eighth Annual IAEE North American Conference on The Changing World Energy Economy, Massachusetts Institute of Technology, Cambridge, MA, November 19-21, 1986; Proc. p. 417 (May 1987)]

A simple energy demand model for the United States has been developed. In the model, goods and services are produced using three factors: fuel, electricity, and capital labor. Fuel and electricity are not perfect substitutes. The tradeoff between fuel and electricity is simulated by using a production function to produce energy from inputs of fuel and electricity. Energy conservation, the tradeoff between energy and capital labor, is simulated by using a production function to produce goods and services from inputs of energy and capital labor.

The model has four parameters and a lifetime for capital stock. The parameters were estimated using data from 1960 to 1982 for values for the lifetime ranging from 4 years to 30 years. The errors are small when the lifetime is greater than 14 years.

Energy demand forecasts were made for two sets of fuel prices: high and low. For the high fuel price case, the model forecasts a steady decline in the demand for fuel. For the low fuel price case, the demand for fuel declines and then rises; by 2010, the demand for fuel is slightly larger than the demand in 1979. For both sets of fuel prices, the demand for electricity grows substantially.

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

4.83

ENERGY SUBSTITUTION PATTERNS IN EMF-8

D. B. Reister

[Abstract in the Proceedings of the Eighth Annual IAEE North American Conference on The Changing World Energy Economy, Massachusetts Institute of Technology, Cambridge, MA, November 19-21, 1986, p. 295 (May 1987)]

A basic tenet of conventional wisdom is that statistically estimated models will have higher price elasticities than models with judgmental parameters. Engineering process models use judgment to incorporate process level engineering information into the model structure. One of the reasons that engineering process models might have low elasticities is that an experienced engineer cannot obtain data for all of the possible ways to substitute one factor for another. The conventional wisdom was confirmed in EMF-4 where the statistically estimated models produced higher elasticity estimates than the models with judgmental parameter estimates.

In the current Energy Modeling Forum (EMF) study of Industrial Energy Demand (EMF-8), long-run elasticity estimates have been obtained from four models. This paper will review the own-price and cross-price elasticity estimates from the four models. The striking

conclusion is that the three models with judgmental parameter estimates (ISTUM-I, ISTUM-II, and ORIM) tend to have higher elasticity estimates than the model with statistically estimated parameters (PURHAPS) or than the estimates in the econometric literature. For example, the estimates of own-price elasticity for natural gas range from -1.3 to -3.4 for the judgmental models and from -0.4 to -1.5 for the estimated models.

Further research is required to resolve the differences between the estimated models and the judgmental models. In EMF-4, the elasticity estimates were for total energy; that is, the substitution of capital, labor and materials for energy. In EMF-8, the elasticity estimates were for fuel substitution. Engineering process models have a better data base for fuel substitution than for energy conservation. A lack of a behavioral detail may cause the judgmental models to overestimate the fuel-substitution elasticity, while a lack of market detail may cause the estimated models to underestimate the fuel-substitution elasticity.

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

4.84

SPECIFICATION OF FUEL SHARE MODELS

D. B. Reister

[Abstract of paper presented at the Eighth Annual IAEE North American Conference on The Changing World Energy Economy, Massachusetts Institute of Technology, Cambridge, MA, November 19-21, 1986; Proc. p. 461 (May 1987)]

In the last decade, many economists have specified and estimated translog fuel share models. However, translog fuel share models have two major deficiencies: cost functions should not be used for engineering fuel share models and a translog function with a high elasticity has a small domain. As a consequence of the second deficiency, an econometric analysis using a translog fuel share model may result in a lower estimate of elasticity than an analysis using another specification.

For an engineering fuel share model, the quantity shares must sum to unity. For a cost function, the cost shares sum to unity. Thus, a cost function should not be used for an engineering fuel share model. A cost function is derived by minimizing the cost of production for a given production function. For the engineering fuel share model, the production function is a linear sum of the fuel types and the minimum cost occurs when the least cost fuel type has a 100% fuel share. Derivation of an engineering fuel share model requires a probabilistic specification, like the logit function.

Fuel share models can have high elasticity; in the limiting case of cost minimization, the elasticity is infinite. A translog function has a limited domain; for a two factor translog function, the maximum price ratio is 1.9 when the elasticity is -2.0 and 1.2 when the elasticity is -6.0 . Thus, if the data set has price ratios that vary from 1.0 to 1.9 , econometric estimation of a translog fuel share model cannot result in an elasticity that is more negative than -2.0 .

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

4.85

THE HYBRID APPROACH TO DEMAND MODELING

D. B. Reister

[Abstract of Chapter 1.3 in *Handbook of Energy Modeling*, Dr. Thomas Kaczmarek, Ed., Pergamon Press (in press)]

This paper presents an engineering-economic approach for developing energy demand models. The approach combines the economic theory of production with engineering process data. We review the economic theory of production, the Constant Elasticity of Substitution (CES) function, and the Logit function. Using the Oak Ridge Industrial Model (ORIM) as a case study, we show how the Logit function can be used to specify a fuel share model and how the CES function can be used to specify an energy conservation model.

Shephard's lemma is a key result of the economic theory of production. The lemma can be used to derive input-output coefficients from a

cost function. We use CES cost functions because they have good global properties. To obtain more flexibility, we use nested CES cost functions. To identify the parameters in a nested CES structure, we assume that the multilevel cost function corresponds to a multistage production process.

When input-output coefficients are derived from a cost function, the tradeoffs between the factors satisfy the law of diminishing returns. Energy conservation occurs when capital, labor or materials are substituted for energy service. In most cases, the substitution obeys the law of diminishing returns. Thus, a CES cost function can be used to specify an energy conservation model.

Normally, perfect substitutes do not obey the law of diminishing returns. Since we include all of the costs for each option in ORIM, the options are perfect substitutes and do not satisfy the law of diminishing returns. Since the options are perfect substitutes, we use the Logit function to specify the ORIM fuel share model.

Research sponsored by U.S. DOE-Fossil Energy Office of Planning and Environment.

4.86

OIL PRODUCTION IN THE UNITED STATES

D. B. Reister

[Abstract of paper presented at the Ninth Annual North American International Association of Energy Economists Meeting, Washington, DC, November 11-13, 1987; Proc. p. 130 (1987)]

The oil price collapse of 1986 has raised concerns over declining domestic production and rising oil imports. In 1987, the Department of Energy (DOE) and the National Petroleum Council (NPC) have published major reports on the impact of low oil prices on the domestic oil industry and on energy security. Supported by DOE, we are developing an engineering-economic model of domestic oil production. The model will help DOE to assess the impact of low oil prices and the outer continental shelf leasing program on domestic production of crude oil.

Research sponsored by U.S. DOE-Fossil Energy, Office of Planning and Environment.

4.87

THE BANG-BANG PRODUCTION OF DEPLETABLE NATURAL RESOURCES

D. B. Reister M. A. S. Gath*

(Abstract of ORNL/TM-10375, April 1987)

This paper reconsiders the problem of determining the optimal production path for a depletable natural resource. The classical result of Hotelling is that the resource owner is indifferent between producing and not producing when the net price of the resource is increasing with the interest rate. However, the sharp increases and decreases in oil price in the last decade illustrate that the net price may not always increase with the interest rate. When the net price is not increasing with the interest rate, the Pontryagin Maximum Principle can be used to extend the classical result to a problem with a bang-bang production schedule and to problems with increasing extraction costs.

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

*University of Tennessee, Knoxville, TN.

4.88

SENSITIVITY ANALYSIS OF ORION

D. B. Reister R. Q. Wright*

(Abstract of ORNL/TM-10198, January 1987)

The replacement cost of oil is the constant selling price that will recover the full expenses of exploration, development, and production of domestic crude oil with a reasonable return on capital. The computer code ORION calculates the replacement cost of oil for 20 regions of the United States: 6 onshore regions and 14 offshore regions. The replacement cost depends on parameters like the finding rate for oil, capital costs, operating costs, tax rates, and the discount rate.

This report presents the results of a sensitivity analysis of ORION. In the analysis, sensitivity coefficients were calculated for all of the parameters in ORION; the coefficients are defined to be

the ratio of the percentage change in the replacement cost to the percentage change of a parameter. The sensitivity analysis of ORION was performed using an automated procedure based on the GRESS precompiler.

For both the offshore and onshore regions, the parameter with the largest sensitivity coefficient was the discount rate. The sensitivity coefficient for the discount rate is approximately equal to the lead-time. Since the lead-times are 3 years for the onshore regions and 5 to 15 years for the offshore regions, the discount rate coefficients can be significantly larger than 1.0.

For the onshore regions, parameters related to oil production (like the reserve discoveries and the number of exploratory wells) had large sensitivity coefficients. For the offshore regions, a weather parameter had large sensitivity coefficients.

Research sponsored by U.S. DOE Office of Advanced Fuels, Technology, Extraction, and Environmental Controls.

*Computing and Telecommunications Division.

4.89

AUTOMATED SENSITIVITY ANALYSIS OF CRESS

L. D. Trowbridge

(Abstract of ORNL/TM-10509, September 1987)

A sensitivity analysis of CRESS (Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation System) has been carried out using an automated sensitivity analysis tool developed at Oak Ridge National Laboratory (ORNL). CRESS, using several linked computer models, projects U.S. commercial and residential sector contributions to the emission of five fossil energy-related atmospheric pollutants. These projections are derived from historical and projected economic and demographic parameters and derived energy use projections.

Sensitivity analyses of three of the key submodels in CRESS have been carried out with the aid of GRESS (GRAdient Enhanced Software System), a tool which automates the direct method of sensitivity analysis. Previous reports in this

series have discussed the analysis results for individual modules of the CRESS system. This report will summarize the individual analyses and examine the linkage of sensitivities through CRESS as a whole to examine the influence on emission projections of selected input projections and control parameters.

Research sponsored by U.S. DOE-Fossil Energy Office of Planning and Environment.

4.90

**SENSITIVITY ANALYSIS OF THE
EMISSION MODULE OF THE
"COMMERCIAL AND RESIDENTIAL
ENERGY USE AND EMISSIONS
SIMULATION SYSTEM" (CRESS)**

L. D. Trowbridge

(Abstract of ORNL/TM-10304, May 1987)

A sensitivity analysis of MODEL6, the final component of the Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation (CRESS) has been carried out using automated sensitivity analysis tools developed at Oak Ridge National Laboratory. MODEL6 projects emissions of five fossil energy-related atmospheric pollutants by assuming emission will be proportional to a related economic activity level adjusted for changes in emission factors. Sensitivities of projections of aggregated emissions to the economic driver parameters and to parameters related to emission factor changes are presented in this report.

Research sponsored by U.S. DOE, Office of Planning and Environment.

4.91

**SENSITIVITY ANALYSIS OF THE
RESIDENTIAL ENERGY USE MODULE
OF THE COMMERCIAL AND RESIDENTIAL
ENERGY USE EMISSIONS SIMULATION
SYSTEM (CRESS)**

L. D. Trowbridge

(Abstract of ORNL/TM-10478, July 1987)

A sensitivity analysis of HOME2, the residential energy use component of Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation (CRESS), has been carried out using an automated sensitivity analysis tool developed at Oak Ridge National Laboratory. HOME2 projects U.S. residential sector energy use from a number of historical and projected economic and demographic parameters. The energy use projections from HOME2 are used in later modules of CRESS to estimate future emissions for five fossil energy-related atmospheric pollutants. Sensitivities of energy use projections to the various driver and control parameters are presented in this report.

Automated sensitivity analysis provides the ability to explore many aspects of model behavior. In the early phases of this study, sensitivity analysis of a predecessor version of HOME2 (June 1986) revealed anomalous behavior in several areas, which led to detection and correction of some difficulties in that version of the residential energy use module of CRESS.

Research sponsored by U.S. DOE Office of Planning and Environment.

4.92

**SENSITIVITY ANALYSIS OF THE
COMMERCIAL ENERGY USE MODULE
OF THE 'COMMERCIAL AND
RESIDENTIAL ENERGY USE
AND EMISSIONS SIMULATION
SYSTEM' (CRESS)**

L. D. Trowbridge

(Abstract of ORNL/TM-10325, March 1987)

A sensitivity analysis of CSEM2, the commercial energy use component of Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation (CRESS) has been carried out using an automated sensitivity analysis tool developed at Oak Ridge National Laboratory. CSEM2 projects U.S. commercial sector energy use from a number of historical and projected economic and demographic parameters. The energy use projections from CSEM2 are used in later modules of CRESS to make projections of emissions for five fossil energy-related atmospheric pollutants. Sensitivities of commercial energy use projections to the various driver and control parameters are presented in this report.

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

4.93

**COMPARISON OF RAMS WORLD OIL
MODEL WITH 'NEPP (1985)
PROJECTIONS TO 2010'**

L. D. Trowbridge

(Abstract of ORNL/TM-10130, August 1985)

The Department of Energy's Office of Policy, Planning, and Analysis recently released a new series of detailed projections of national and world energy trends (NEPP-85). This study presents a comparison of the behavior of the RAMS World Oil Model with the NEPP-85 results. Two goals were defined for this study: (1) determine the changes necessary to RAMS input parameters to approximately duplicate

NEPP-85 results, and (2) determine effect of replacing the existing input assumptions in the standard version of RAMS with corresponding NEPP-85 assumptions.

The changes made to RAMS in this study were to the numeric values of the standard scenario parameters. In no case were the model equations altered.

The results that are compared in this analysis are the projected trajectories of World Oil Price and (non-communist) World Oil Production. In general, as will be seen below, the RAMS model, with appropriate parameter adjustments, appears to be able to do a reasonable job of duplicating the long-term trends found in the NEPP-85 study. It does less well at duplicating the detailed short-term behavior ('85-'90) of NEPP-85.

Research sponsored by U.S. DOE Office of Oil, Gas, Shale, and Coal Liquids.

4.94

**RAMS WORLD OIL MODEL: A
PC-BASED MODEL OF THE
PENETRATION OF UNCONVENTIONAL
OIL INTO THE WORLD OIL MARKET**

**L. D. Trowbridge E. Hicks*
J. V. Comopask***

(Abstract of paper presented at the International Forum on Coal Liquefaction, Atlanta, GA, April 7-11, 1986)

This document is intended to provide an overview of the RAMS (Research and Development Analysis and Modeling System) World Oil Model. This model is designed to be a tool to aid in planning of unconventional liquid fuel R&D programs. It is intended to provide a relatively simple, qualitative framework simulating long-term trends in the world oil market within which market penetration of alternative synthetic and unconventional fuels may be studied. The model design emphasizes robustness, flexibility, and transparency; it is not intended to be a quantitative tool for precise projection of future oil markets. The model is implemented as a Lotus 1-2-3 spreadsheet on an IBM PC.

The purpose of the model is to permit study of the penetration of unconventional oil into the world market. The means chosen to accomplish this was to devise a supply/demand equilibrium model of the world oil market (excluding the internal interactions of countries with centrally planned economies) for the 50-year period from 1980 to 2030. The supply of oil from 24 regional sources and 15 unconventional fuel technologies is balanced against oil demand from three aggregate world regions to calculate world oil production and price tracks. When the world oil price exceeds the cost of an unconventional source of oil, it will penetrate the market at a rate determined by timing and production growth parameters.

Research sponsored by U.S. DOE Office of Gas, Shale, and Coal Liquids.

*Applied Management Sciences, Inc., Silver Springs, MD.

4.95

PENETRATION OF UNCONVENTIONAL OIL INTO WORLD MARKETS

**L. D. Trowbridge D. B. Reister
J. V. Conopask* E. Hicks***

[Abstract of paper presented at the Eighth Annual IAEE North American Conference on The Changing World Energy Economy, Massachusetts Institute of Technology, Cambridge, MA, November 19-21, 1986; Proc. p. 130 (May 1987)]

The Nonconventional Liquid Fuels Research and Development Analysis Modeling System (RAMSOIL) was developed for the U.S. Department of Energy, Office of Fossil Energy, to be a scenario analysis tool to aid in planning of unconventional liquid fuel R&D programs. RAMSOIL

was the first in a series of such models. The second, RAMSGAS, will be discussed in a separate paper, and a coal model is under development. RAMSOIL is intended to provide a relatively simple, qualitative framework simulating long-term trends in the world oil market within which market penetration of alternative synthetic and nonconventional fuels may be studied. The model design emphasizes robustness, flexibility, and transparency; it is not intended to be a quantitative tool for precise projection of future oil markets. The model is implemented as a Lotus 1-2-3 spreadsheet on an IBM-PC.

The purpose of the model is to permit study of the penetration of unconventional oil into the world market. The means chosen to accomplish this was to devise a supply/demand partial equilibrium model of the world oil market (excluding the internal interactions of countries with centrally planned economies) for the 50-year period from 1980 to 2030. The supply of oil from 24 regional sources and 15 unconventional fuel technologies is balanced against oil demand from three aggregate noncommunist world regions to calculate world oil production and price tracks. When the world oil price exceeds the cost of an unconventional source of oil, the unconventional source will penetrate the market at a rate determined by parameters governing production growth and technology availability.

The ability of RAMSOIL to reproduce a published scenario produced by a more elaborate set of models has been demonstrated.

Research sponsored by U.S. DOE Fossil Energy, Office of Planning and Environment.

*Applied Management Sciences, Inc., Silver Spring, MD.

Sensitivity Analysis Methodology and Applications

4.96

APPLICATION OF ADJOINT SENSITIVITY THEORY TO AN ATMOSPHERIC GENERAL CIRCULATION MODEL

M. C. G. Hall

[Abstract of *J. Atmospheric Sciences* 43(22), 2644 (1986)]

Sensitivity studies with climate models usually involve rerunning the model. Since climate models take so much computer time, this approach can be used to calculate sensitivities to only a few parameters. This work demonstrates the use of a much more efficient method of estimating sensitivities — the adjoint method. About a hundred first order parameter sensitivities can be estimated with the same amount of computer time as a single integration of the model.

The adjoint method is applied to the Oregon State University atmospheric general circulation model. Sensitivities estimated using the adjoint method agree within 20% to those calculated directly by rerunning. In addition, the contribution to each parameter sensitivity is broken down by the adjoint method into its temporal, physical and spatial components. The main conclusions of this work are (a) the adjoint method is feasible with the right approximations for models as large as general circulation models, and (b) the sensitivity information revealed by the adjoint method is useful in helping understand the results of climate models.

Research sponsored by U.S. DOE Carbon Dioxide Research Division, Office of Basic Energy Sciences.

4.97

UPGRADE OF THE GRESS (TEST VERSION D) PRECOMPILER TO ALLOW TRIPLY-DIMENSIONED ARRAYS

J. E. Horwede^{*} F. G. Pim

(Abstract of ORNL/CSD/TM-240, December 1986)

GRESS is a FORTRAN precompiler and run-time library which automatically processes computer models and adds derivative-taking capabilities to the normal calculated results. The GRESS system is under development at ORNL and work is proceeding in upgrading test versions of the precompiler to allow processing by GRESS of most of the ANSI X3.9-1978 FORTRAN syntax. Heretofore, a major limitation has been the inability of GRESS to process arrays with more than two dimensions. Consequently, a significant amount of human effort was required to convert three- and higher-dimensional arrays into two-dimensional arrays for processing with GRESS. This report describes the addition of ten operation codes to the GRESS precompiler and run-time library to allow application to FORTRAN programs with three-dimensional arrays. The new operation codes were tested on a sample problem. A comparison of CPU time is made for sample problems run on a VAX 8600 computer with one-, two-, and three-dimensional arrays. It is recommended that GRESS be further modified to accommodate higher-dimensional arrays up to the ANSI X3.9-1978 limit of seven dimensions.

Research sponsored by the Computing and Telecommunications Division.

^{*} Computing and Telecommunications Division.

4.98

SUPERTRACKS: THE BUILDING BLOCKS OF CHAOS

E. M. Oblow

(Abstract of ORNL/TM-10550, August 1987)

A theoretical conjecture is made about the nature of chaotic behavior in systems with simple maps. This conjecture gives rise to a computational scheme based on trajectories starting from the maximum in the system map. These trajectories are called *supertracks* and their loci in the parameter phase-space indexed by iteration number are called *supertracks functions*. The chaotic regimes of two nonlinear systems with a single maximum are studied using this scheme. It is found that the behavior in these regimes can be characterized recursively by supertrack functions. At low recursion order these functions analytically describe the gross features of the chaotic regime (i.e., bounding envelopes, stable cycles, star points, etc.). They can be iterated to higher orders to study higher order features. The methodology employed is general enough to be used to study other nonlinear systems. It also has potential for identifying chaotic behavior experimentally. Universality is the basis for theoretical understanding the results.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.99

AUTOMATING SENSITIVITY ANALYSIS OF COMPUTER MODELS USING COMPUTER CALCULUS

E. M. Oblow F. G. Pin

(Abstract of paper presented at the Seventh Annual DOE/LLW Participant's Information Meeting, Las Vegas, NV, September 11-13, 1985)

An automated procedure for performing sensitivity analyses has been developed. The procedure uses a new FORTRAN compiler with computer calculus capabilities to generate the derivatives needed to set up sensitivity equations.

The new compiler is called GRESS — GRAdient Enhanced Software System. Application of the automated procedure with "direct" and "adjoint" sensitivity theory for the analysis of nonlinear, iterative systems of equations is discussed. Computational efficiency consideration and techniques for adjoint sensitivity analysis are emphasized. The new approach is found to preserve the traditional advantages of adjoint theory while removing the tedious human effort previously needed to apply this theoretical methodology. Conclusions are drawn about the applicability of the automated procedure in numerical analysis and large-scale modeling sensitivity studies.

Research sponsored by U.S. DOE Office of Defense Waste and By-Products Management.

4.100

SENSITIVITY ANALYSIS USING COMPUTER CALCULUS: A NUCLEAR WASTE ISOLATION APPLICATION

**E. M. Oblow F. G. Pin
R. Q. Wright***

[Abstract of *Nucl. Sci. Eng.* 94, 46 (1986)]

An automated procedure for performing large-scale sensitivity studies based on the use of computer calculus is presented. The procedure is embodied in a FORTRAN precompiler called GRESS, which automatically processes computer models to add derivative-taking capabilities to the normal calculated results. In this paper, the theory and applicability of the GRESS code are described and tested against a major geohydrological modeling problem. The SWENT nuclear waste repository modeling code is used as the basis for these studies. Results for a test problem involving groundwater flow in the vicinity of the Richton Salt Dome are discussed in detail. Conclusions are drawn as to the applicability of GRESS in the problem studied and for more general large-scale modeling sensitivity studies.

Research sponsored by U.S. DOE Office of Defense Waste and By-Products Management.

*Computing and Telecommunications Division.

4.101

AUTOMATED SENSITIVITY ANALYSIS: NEW TOOLS FOR MODELING COMPLEX DYNAMIC SYSTEMS

F. G. Pim

[Abstract of paper presented at the Energy Division Specialty Conference on Energy 87, Energy Solutions Today for the Nineties, American Society of Civil Engineers, Atlantic City, NJ, April 27-30, 1987; Proc. p. 305 (1987)]

Sensitivity analysis is an established methodology used by researchers in almost every field to gain essential insight in design and modeling studies and in performance assessments of complex systems. Conventional sensitivity analysis methodologies, however, have not enjoyed the widespread use they deserve considering the wealth of information they can provide, partly because of their prohibitive cost or the large initial analytical investment they require. Automated systems have recently been developed at ORNL to eliminate these drawbacks. Compilers such as GRESS and EXAP now allow automatic and cost effective calculation of sensitivities in FORTRAN computer codes. In this paper, these and other related tools are described and their impact and applicability in the general areas of modeling, performance assessment and decision making for radioactive waste isolation problems are discussed.

Research sponsored by U.S. DOE Salt Repository Project Office.

4.102

ADGEN: A SYSTEM FOR AUTOMATED SENSITIVITY ANALYSIS OF PREDICTIVE MODELS

F. G. Pim J. E. Horwedel*
E. M. Oblow J. L. Lucius*

[Abstract of paper presented at the Eighth Annual DOE Low-Level Waste Management Forum, Denver, CO, September 22-26, 1986; Proc. Technical Session V, Performance Assessment, p. 86 (February 1987)]

A system that can automatically enhance computer codes with a sensitivity calculation capability is presented. With this new system,

named ADGEN, rapid and cost-effective calculation of sensitivities can be performed in *any* FORTRAN code for *all* input data or parameters. The resulting sensitivities can be used in performance assessment studies related to licensing or interactions with the public to systematically and quantitatively prove the relative importance of each of the system parameters in calculating the final performance results. A general procedure calling for the systematic use of sensitivities in assessment studies is presented. The procedure can be used in modelling and model validation studies to avoid "over modelling," in site characterization planning to avoid "over collection of data," and in performance assessments to determine the uncertainties on the final calculated results. The added capability to formally perform the inverse problem, i.e., to determine the input data or parameters on which to focus additional research or analysis effort in order to improve the uncertainty of the final results, is also discussed.

Research sponsored by U.S. DOE Office of Defense Waste and Transportation Management.

* Computing and Telecommunications Division.

4.103

SENSITIVITY ANALYSIS OF PREDICTIVE MODELS WITH AN AUTOMATED ADJOINT GENERATOR

F. G. Pim E. M. Oblow

(Abstract of paper presented at the Ninth Annual DOE Low-Level Radioactive Waste Management Conference, Denver, CO, August 25-27, 1987)

The adjoint method is a well established sensitivity analysis methodology which is particularly efficient in large-scale modeling problems. Its efficiency comes from the fact that the coefficients of sensitivity of a given response with respect to every parameter involved in the modeling code can be calculated from the solution of a single adjoint run of the code. Sensitivity coefficients provide a quantitative measure of the importance of the model data in calculating the final results. The major drawback of the adjoint method which has prevented its widespread use in computational systems is the requirement for cal-

culations of very large numbers of partial derivatives in order to set up the adjoint equations of the model. ADGEN is a software system which has been designed to eliminate this drawback and automatically implement the adjoint formulation in computer codes. In this paper, the ADGEN system will be described and its use for improving performance assessment and predictive simulations will be discussed.

Research sponsored by U.S. DOE National Low-Level Waste Management Program.

4.104

ADGEN: AN AUTOMATED ADJOINT CODE GENERATOR FOR LARGE-SCALE SENSITIVITY ANALYSIS

F. G. Pin E. M. Oblow
J. E. Horwedel* J. L. Lucias*

[Abstract of *Trans. Am. Nucl. Soc.* 55, 311 (1987)]

This paper describes a new automated system, named ADGEN, which makes use of the strengths of computer calculus to automate the costly and time-consuming calculation of derivatives in FORTRAN computer codes and automatically generate adjoint solutions of computer programs.

ADGEN uses an Extended Arithmetic Processor to automatically enhance any FORTRAN code with the additional lines of coding necessary to calculate all required derivatives for the adjoint formulation. At execution of the enhanced code, ADGEN automatically manages the storage of the derivatives and sets up the adjoint equations as a large matrix equation. The adjoint solution is then calculated using efficient back-substitution techniques and is used to obtain all sensitivities of interest through straightforward vector calculations. The efficiency of the overall system increases with the number of required sensitivities, and problems that were practically unapproachable with the "direct" approach can now be done in routine fashion. Examples of the use of the ADGEN system on sample adjoint problems will be presented and the applicability

of the system to a more general class of problems will be discussed.

Research sponsored by U.S. DOE Office of National Low-Level Waste Management.

*Computing and Telecommunications Division.

4.105

AUTOMATED SENSITIVITY ANALYSIS USING THE GRESS LANGUAGE

F. G. Pin E. M. Oblow
R. Q. Wright*

(Abstract of ORNL-6148, April 1986)

An automated procedure for performing large-scale sensitivity studies based on the use of computer calculus is presented. The procedure is embodied in a FORTRAN precompiler called GRESS, which automatically processes computer models and adds derivative-taking capabilities to the normal calculated results. In this report, the GRESS code is described, tested against analytic and numerical test problems, and then applied to a major geohydrological modeling problem. The SWENT nuclear waste repository modeling code is used as the basis for these studies. Results for all problems are discussed in detail. Conclusions are drawn as to the applicability of GRESS in the problems at hand and for more general large-scale modeling sensitivity studies.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

*Computing and Telecommunications Division.

4.106

AN AUTOMATED SENSITIVITY ANALYSIS PROCEDURE FOR THE PERFORMANCE ASSESSMENT OF NUCLEAR WASTE ISOLATION SYSTEMS

F. G. Pin B. A. Worley
E. M. Oblow R. Q. Wright*
W. V. Harper*

[Abstract of *Nucl. Chem. Waste Manage. J.* 6, 255 (1986)]

The licensing of proposed high-level nuclear waste isolation facilities requires in-depth analysis

of the expected performance and associated risks of the isolation system. Owing to the large uncertainties generally associated with the data characterizing geologic media and waste behavior and to the predictive nature of the simulations supporting the assessment, sensitivity and uncertainty analyses are necessary components of the overall performance assessment activities. Sensitivity analyses also play a major role in the identification of important parameters and of specific data needs for site characterization. To support an effort in making large-scale sensitivity analyses feasible, cost efficient and quantitatively complete, we have developed an automated procedure making use of computer calculus. The procedure, called GRESS (GRAdient Enhanced Software System), is a precompiler that can process FORTRAN computer codes and add derivative-taking capabilities to the normal calculated results. In this paper, the automated GRESS procedure is described and applied to the code UCB-NE-10.2, which simulates the migration through a sorption medium of the radionuclide members of a decay chain. Conclusions are drawn relative to the applicability of GRESS for more general large-scale sensitivity studies, and the role of such techniques in an overall sensitivity and uncertainty analysis program is discussed.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

* Computing and Telecommunications Division.

4.107

GRESS TRANSLATION OF THE ORIGEN2 CODE

F. G. Pin R. Q. Wright*

(Abstract of ORNL/TM-9694, May 1986)

ORIGEN2 is a widely used point-depletion and radioactive-decay computer code for use in simulating nuclear fuel cycles and/or spent fuel characteristics. In typical applications the code calculates chain buildup and decay of more than 1600 radionuclides and elements. This report describes the addition to the ORIGEN2 code of

an automated sensitivity calculation capability by means of the GRESS precompiler. The GRESS precompiler uses computer calculus to automatically enhance FORTRAN computer codes with derivative-taking capabilities. From these derivatives generated concurrently with the normal results, sensitivities of any variable used in the code with respect to any other variable or input parameter can readily be obtained. The added sensitivity calculation capability is verified on a sample problem involving fuel burnup under specified power, radioactive decay, and material irradiation under specified flux. The accuracy of the GRESS results is demonstrated using comparisons with the results of perturbation analyses.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

* Computing and Telecommunications Division.

4.108

A WASTE PACKAGE PERFORMANCE ASSESSMENT CODE WITH AUTOMATED SENSITIVITY-CALCULATION CAPABILITY

B. A. Worley J. E. Horwedel*

(Abstract of ORNL/TM-9976, September 1986)

WAPPA-C is a waste package performance assessment code that predicts the temporal and spatial extent of the loss of containment capability of a given waste package design. This code was enhanced by the addition of the capability to calculate the sensitivity of model results to any parameter. The GRESS automated procedure was used to add this capability in only two man-months of effort. The verification analysis of the enhanced code, WAPPAG, showed that the sensitivities calculated using GRESS were accurate to within the precision of perturbation results against which the sensitivities were compared. Sensitivities of all summary table values to eight diverse data values were verified.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

* Computing and Telecommunications Division.

4.109

**DETERMINISTIC METHODS FOR
SENSITIVITY AND UNCERTAINTY
ANALYSIS IN LARGE-SCALE
COMPUTER MODELS**

B. A. Worley E. M. Obrow
F. G. Pin R. E. Maerker
J. E. Horwedel* R. Q. Wright*
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(Abstract of paper presented at the DOE/AECL Sensitivity and Uncertainty Conference, San Francisco, CA, September 9-14, 1987)

The fields of sensitivity and uncertainty analysis have traditionally been dominated by statistical techniques when large-scale modeling codes are being analyzed. These methods are able to estimate sensitivities, generate response surfaces, and estimate response probability distributions given the input parameter probability distributions. Because the statistical methods are computationally costly, they are usually applied only to problems with relatively small parameter sets. Deterministic methods, on the other hand, are very efficient and can handle large data sets, but generally require simpler models because of the considerable programming effort required for their implementation. The first part of this paper reports on the development and availability of two systems, GRESS and ADGEN, that make use of computer calculus compilers to automate the implementation of deterministic sensitivity analysis capability into existing computer models. This automation removes the traditional limitation of deterministic sensitivity methods. The second part of the paper describes a deterministic uncertainty analysis method (DUA) that uses derivative information as a basis to propagate parameter probability distributions to obtain result probability distributions. The last part of the paper demonstrates the deterministic approach to sensitivity and uncertainty analysis as applied to a sample problem that models the flow

of water through a borehole. The sample problem is used as a basis to compare the cumulative distribution function of the flow rate as calculated by the standard statistical methods and the DUA method. The DUA method gives a more accurate result based upon only two model executions compared to fifty executions in the statistical case.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

* Computing and Telecommunications Division.

4.110

**A VERSION OF ORIGEN2
WITH AUTOMATED
SENSITIVITY-CALCULATION
CAPABILITY**

B. A. Worley R. Q. Wright*
F. G. Pin

[Abstract of *Trans. Am. Nucl. Soc.* 52, 438 (1986)]

The ORIGEN2 code is a widely used point-depletion and radioactive-decay computer code for use in simulating nuclear fuel cycles and/or spent fuel characteristics. A new version of ORIGEN2, ORIGEN2G, is now available that has the capability to calculate derivatives of any user-specified real variable with respect to another variable or input parameter. By using the GRESS precompiler, we were able to automate almost all of the effort of producing ORIGEN2G and thus dramatically reduce the initial analytical effort that would have been required in programming a code of comparable capability. The ability to calculate all partial derivatives on demand in ORIGEN2G opens new avenues of study that would have been unfeasible using the conventional sensitivity technique of performing numerous recalculations.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

* Computing and Telecommunications Division.

4.111

A FINITE-LINE HEAT TRANSFER CODE WITH AUTOMATED SENSITIVITY-CALCULATION CAPABILITY

B. A. Worley R. Q. Wright*
F. G. Pin

(Abstract of ORNL/TM-9975, September 1986)

The finite-line heat transfer code, TEMP, is used to calculate temperature distributions within geological repositories for high level nuclear waste. A capability to concurrently calculate the sensitivity of the temperature distribution to any or all data of interest was incorporated into this code using an automated procedure called GRESS. Only two man-weeks of effort were required for this process. The accuracy of the GRESS-added sensitivity calculation capability was verified using comparisons of GRESS-calculated sensitivities with sensitivities estimated from perturbation analysis for all 189 TEMP sample cases. This successful GRESS enhancement of TEMP and the associated verification analysis contributes to the overall program of validating the GRESS procedure.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

*Computing and Telecommunications Division.

4.112

APPLICATION OF AN AUTOMATED PROCEDURE FOR ADDING A COMPREHENSIVE SENSITIVITY CALCULATION CAPABILITY TO THE ORIGEN2 POINT DEPLETION AND RADIOACTIVE DECAY CODE

B. A. Worley R. Q. Wright*
F. G. Pin W. V. Harper†

[Abstract of Nucl. Sci. Eng. 94, 180 (1986)]

An application of an automated procedure called GRESS for adding derivative-taking capability to FORTRAN computer codes is presented. The efficiency and usefulness of GRESS in enhancing the point-depletion and radioactive decay code ORIGEN2 is discussed. A new ver-

sion of ORIGEN2 is now available that has the capability of calculating first derivatives and sensitivities of any variable in the code with respect to any other variable. The capabilities of the enhanced version, ORIGEN2G, are exemplified by its use in a sensitivity study of a high-level nuclear waste disposal problem. By using GRESS, the enhanced version ORIGEN2G was produced, tested, and verified in two man-months compared to an estimated one to two man-years effort to program a code with comparable capabilities.

Research sponsored by U.S. DOE Office of Defense Waste and By-Products Management.

*Computing and Telecommunications Division.

†Office of Nuclear Waste Isolation, Columbus, OH.

4.113

AN AUTOMATED PROCEDURE FOR CALCULATING TIME-DEPENDENT SENSITIVITIES IN ORIGEN2

B. A. Worley R. Q. Wright*

(Abstract of ORNL/TM-9771, October 1985)

ORIGEN2 is a widely used point-depletion and radioactive-decay computer code for use in simulating nuclear fuel cycles and/or spent fuel characteristics. This paper presents the application of the GRESS procedure to the ORIGEN2 code for performing a sensitivity analysis of a high-level waste disposal problem. The GRESS procedure uses computer calculus and the GRESS precompiler to automate the generation and calculation of gradients in a computer code. The GRESS version of ORIGEN2 is used to calculate the nuclide-dependent sensitivities of the decay heat and radioactivity of 1,008 nuclides comprising reprocessed high-level waste to changes in data and input parameters. The sensitivities are calculated in a single execution of the revised code as compared to the conventional method of rerunning the code numerous times. The availability of sensitivity data as an option in ORIGEN2 reveals relationships not easily recognized even with reruns.

Research sponsored by U.S. DOE Office of Breeder Reactor Systems.

*Computing and Telecommunications Division.

4.114

CHARACTERIZATION PLAN FOR SOLID WASTE STORAGE AREA 6

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E. D. Smith^{*}

(Abstract of ORNL/TM-9877, December 1985)

Solid Waste Storage Area 6 (SWSA-6) is the only currently operating low-level radioactive waste (LLW) shallow land burial facility at the Oak Ridge National Laboratory. The U.S. Department of Energy (DOE) recently issued DOE Order 5820.2, which provides new policy and guidelines for the management of radioactive wastes. To ensure that SWSA-6 complies with this order, it will be necessary to establish whether sufficient data on the geology, hydrology, soils, and climatology of SWSA-6 exist, and to develop plans to obtain any additional information required. It will also be necessary to establish a source term from the buried waste and provide geochemical information for hydrologic and dosimetric calculations. Where data gaps exist, methodology for obtaining this information must be developed. The purpose of this plan is to review existing information on SWSA-6 and develop cost estimates and schedules for obtaining any required additional information.

Routine operation of SWSA-6 was initiated in 1973, and it is estimated that about 29,100 m³ (1,000,000 ft³) of LLW containing about 250,000 Ci of radioactivity have been buried through 1984. Both low-activity and high-activity level wastes were buried in trenches and auger holes at the site. It is possible that before 1980, wastes were buried that would be considered hazardous wastes under the Resource Conservation and Recovery Act. Since SWSA-6 was sited prior to enactment of current disposal regulations, a detailed site survey of the geologic and hydrologic properties of the site was not performed before wastes were buried. However, during the opera-

tion of SWSA-6 some information on site characteristics has been collected as a result of various research and development programs aimed at improving disposal practices and of attempts to investigate corrective actions. This information is useful in understanding the existing problems at the site; however, in many cases, the information is not complete enough to allow a detailed analysis of the long-term performance of the site for compliance purposes.

Plan and cost estimates have been developed to provide the information necessary to conduct a performance assessment of the site. The plan is based on a two-year data collection period at an estimated cost of \$1,650,000.00.

Research sponsored by U.S. DOE Office of Defense Waste and Byproducts Management

^{*}Environmental Sciences Division.

[†]Chemical Technology Division.

[‡]Health and Safety Research Division.

4.115

SUMMARY OF THE WASTE MANAGEMENT PROGRAMS AT URANIUM RECOVERY FACILITIES AS THEY RELATE TO THE 40 CFR PART 192 STANDARDS

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(Abstract of ORNL/TM-9797 (NUREG/CR-4403), November 1985)

This study evaluates the degree to which surface impoundments at licensed facilities comply with significant changes in NRC requirements initiated by enactment of EPA's final environmental standards for uranium recovery facilities (40 CFR Part 192). Impoundment liner requirements, groundwater protection standards, groundwater monitoring and corrective action programs, and site closure standards are the most significant regulatory modifications.

The compliance status of 30 conventional mills and 31 *in-situ* mines is determined from a review of Nuclear Regulatory Commission and agreement state docket files through November

1983. Results of this review show that a majority of conventional uranium mill tailings management systems are deficient with respect to liner requirements for new impoundments or proposed expansions to existing impoundments, as well as with respect to some aspects of groundwater monitoring and compliance programs. Furthermore, the status of conventional mill site closure plans is highly uncertain at this time. Although surface impoundments at *in-situ* uranium mines also are deficient with respect to groundwater monitoring programs, they generally comply with other changes in requirements imposed by 40 CFR Part 192.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards.

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†Energy Division.

4.116

**RECENT ORNL EXPERIENCE IN
SITE PERFORMANCE PREDICTION:
THE GAS CENTRIFUGE ENRICHMENT
PLANT AND THE OAK RIDGE
CENTRAL WASTE DISPOSAL FACILITY**

F. G. Piu

(Abstract of paper presented at the DOE/CEA Information Exchange Workshop on Low-Level Waste Siting and Characterization, Paris, France, September 30 - October 3, 1985)

The suitability of the Portsmouth Gas Centrifuge Enrichment Plant Landfill and the Oak Ridge, Tennessee, Central Waste Disposal Facility

for disposal of low-level radioactive waste was evaluated using pathways analyses. For these evaluations, a conservative approach was selected; that is, conservatism was built into the analyses when assumptions concerning future events had to be made or when uncertainties concerning site or waste characteristics existed.

Data from comprehensive laboratory and field investigations were used in developing the conceptual and numerical models that served as the basis for the numerical simulations of the long-term transport of contamination to man. However, the analyses relied on conservative scenarios to describe the generation and migration of contamination and the potential human exposure to the waste. Maximum potential doses to man were calculated and compared to the appropriate standards. Even under this conservative framework, the sites were found to provide adequate buffer to persons outside the DOE reservations and conclusions concerning site capacity and site acceptability were drawn.

Our experience through these studies has shown that in reaching conclusions in such studies, some consideration must be given to the uncertainties and conservatisms involved in the analyses. Analytical methods to quantitatively assess the probability of future events to occur and to quantitatively determine the sensitivity of the results to data uncertainty may prove useful in relaxing some of the conservatism built into the analyses. The applicability of such methods to pathways analyses is briefly discussed.

Research sponsored by U.S. DOE Office of Defense Waste and By-Products Management.

Radiation Dosimetry and Reactor Physics

4.117

LEPRICON ANALYSIS OF PRESSURE
VESSEL SURVEILLANCE DOSIMETRY
INSERTED INTO H. B. ROBINSON-2
DURING CYCLE 9

R. E. Maerker

[Abstract of ORNL/TM-10132 (NUREG/CR-4439), August 1986; also *Nucl. Sci. Eng.* 96, 263 (1987); also paper entitled "Application of the LEPRICON Methodology to LWR Pressure Vessel Surveillance Dosimetry," presented at the Sixth ASTM-EURATOM Symposium on Reactor Dosimetry, Jackson Hole, WY, May 31 - June 5, 1987]

A second example of applying the LEPRICON methodology to an existing pressurized water reactor is described. The present application is an analysis of *ad hoc* dosimetry inserted into the H. B. Robinson-2 reactor to monitor the effects on pressure vessel fluence produced by the introduction of a low-leakage fuel management scheme during cycle 9. The use of simultaneous dosimetry at both a downcomer location and in the reactor cavity allows a quantitative evaluation to be made by the LEPRICON procedure of the relative merits of each location, and the cavity location is found to be superior. Unfolded results using the dosimetry indicate that the cumulative neutron fluence above 1.0 MeV originally calculated for the critical lower circumferential weld in the pressure vessel during cycle 9, $7.2 \times 10^{17} \text{ n/cm}^2 \pm 15.9 \text{ percent}$, should be adjusted upward by about one standard deviation to a value of $8.8 \times 10^{17} \text{ n/cm}^2$ with a reduced uncertainty of 10.9 percent.

Research sponsored by U.S. Nuclear Regulatory Commission.

4.118

ANALYSIS OF THE NESDIP2 AND
NESDIP3 RADIAL SHIELD AND
CAVITY EXPERIMENTS

R. E. Maerker

[Abstract of ORNL/TM-10389 (NUREG/CR-4886), May 1987]

Discrete ordinates calculations were made of a series of measurements performed using the NESTOR reactor at AEE Winfrith. These measurements are part of the NESDIP experimental program designed to benchmark methods and data commonly used in interpreting pressure vessel surveillance dosimetry placed at either in-vessel or ex-vessel locations. Results obtained using the LEPRICON procedures and updated ELXSIR cross sections indicate agreement to within about 10 percent with measured threshold dosimeter activities found various components of a radial shield containing up to 25 cm of water and 24 cm of steel. Significant discrepancies in the energy range between 0.1 and 2 MeV were found to exist with measurements made on the centerline of a 20-cm-wide cavity and at vertical locations considerably above the centerline of a 21-cm-wide cavity, however. A logical explanation of the latter discrepancy is the failure of two independent two-dimensional calculations to properly treat the three-dimensional effects of vertical cavity streaming. No satisfactory explanation has yet surfaced for the first discrepancy, however, which is the more important of the two in possibly affecting the interpretation of ex-vessel, low threshold ($\sim 100 \text{ keV}$) dosimetry.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

4.119

LEPRICON ANALYSIS OF THE ASPIS-PCA SLAB GEOMETRY BENCHMARKS

R. E. Maerker

[Abstract of *Trans. Am. Nucl. Soc.* 55, 551 (1987)]

An analysis has been made of a series of benchmark measurements performed in the ASPIS facility at AEE, Winfrith. The analysis reported here is of the NESDIP2 experiment, which consists primarily of dosimetry measurements at various positions throughout a radial shield mock-up. The radial shield is virtually identical to the "12/13" configuration previously analyzed using the Pool Critical Assembly (PCA) at Oak Ridge, but improves on the earlier geometry in that the increased lateral dimensions of the slabs relative to those of the source permits an accurate RZ transport analysis to be made.

The transport analysis consisted of the use of two cross-section sets which were identical except for iron. The first set was based on ENDF/B-IV and is the standard ELXSIR library used in the LEPRICON methodology. The second set used an updated ENDF/B-V MOD 4 iron evaluation by C. Y. Fu.

The analysis also employed two different geometries in the DOT4.3 transport code, RZ and a synthesized XYZ. The synthesis combines the results of three discrete ordinates calculations, XZ, YZ, and Z, using the same procedure as the one adopted in the LEPRICON methodology for ROZ geometry and used in LWR pressure vessel dosimetry analysis.

The four sets of calculations are compared with the measurements for the high-threshold sulfur and low-threshold rhodium dosimeters. In these calculations, a weighted difference (sometimes referred to as zero-weighted as compared to theta-weighted) flux extrapolation model was used. Subsequently, it was found that the use of theta weighting increased the RZ activities by about 5%.

Major conclusions are the improved accuracy of the updated iron set, the adequacy of the syn-

thesis procedure over the centerline locations investigated, and the onset of a significant, sudden, and as yet unexplained underprediction of around 25% in the rhodium cavity activity. This discrepancy is of great concern, for it may affect the accuracy of the interpretation of future LWR ex-vessel dosimetry.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

4.120

ACCOUNTING FOR CHANGING SOURCE DISTRIBUTIONS IN LIGHT WATER REACTOR SURVEILLANCE DOSIMETRY ANALYSIS

R. E. Maerker M. L. Williams*
B. L. Broadhead†[Abstract of *Nucl. Sci. Eng.* 94, 291 (1986)]

A technique is described to account for effects of space- and time-dependent core source variations on pressure vessel surveillance dosimetry analysis. The procedure first defines an easily implemented geometry for a single adjoint transport calculation. The results from the adjoint calculation can then be combined with those from a single forward calculation, in conjunction with 2n adjoint scaling technique, to yield activities and pressure vessel fluxes simultaneously for a wide range of source distributions, dosimeter response functions, and detector locations. This method has been implemented in the LEPRICON code system for vessel fluence determination. An application to an R-θ model of an operating power reactor shows that effects of source perturbations resulting in 20% changes in the core leakage can be predicted within about three percent at both downcomer and cavity dosimeter locations, for six different dosimeters, by choice of a single suitable adjoint response function.

Research sponsored by Electric Power Research Institute.

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†Computing and Telecommunications Division.

4.121

VALIDATION OF CELL ANALYSIS CAPABILITY USING ENDF/B-V NUCLEAR DATA

**M. L. Williams* B. A. Worley
R. Q. Wright†**

(Abstract of EPRI NP-4806, September 1986)

A new version of the lattice physics code EPRI-CELL has recently been developed and pre-released by EPRI under the name CELL-2. One of the important features of this code is that it provides an option for utilizing a new set of cross section libraries based on ENDF/B-V data, the most recently compiled evaluated cross-section file by the U.S. National Nuclear Data Center. Several improvements have also been made to the lattice physics approximations in the code in order to take full advantage of the more accurate nuclear data.

This report summarizes the work which resulted in CELL-2 (referred to in this report as the ENDF/B-V version of EPRI-CELL), including the ENDF/B-V data testing, library generation, methods improvements, and code benchmarking. The new ENDF/B-V multigroup library is compared to the original EPRI-CELL library and differences are discussed. The results of a methods validation program are given in which EPRI-CELL calculations of integral parameters and multigroup cross sections are compared to rigorous transport theory calculations of numerical benchmark problems. EPRI-

CELL is used to compute isolated rod resonance integrals based on ENDF/B-V, which are then compared with experimental values. The results of a comprehensive reactor benchmarking study are given for clean UO_2 and MO_2 criticals and for hot zero power PWR cores. Results of depletion calculations are compared with experimentally measured isotopic ratios for three power reactor cores.

It is concluded that the ENDF/B-V version of EPRI-CELL is a very accurate lattice physics code for LWR calculations. The new EPRI-CELL methods produce excellent agreement with more sophisticated codes which require much longer running times. The adequacy of the ENDF/B-V data used in EPRI-CELL is verified by the good agreement with measured resonance integrals and reaction rate ratios. The critical eigenvalues for a wide variety of UO_2 and MO_2 criticals are accurately computed. Generally the ENDF/B-V version of the code produces more consistent results than the original version, and it does not contain any arbitrarily adjusted data or methods. The depletion benchmark calculations validate that the buildup of plutonium isotopes in power reactors can be accurately predicted for a wide range of problems. Overall, the performance of the ENDF/B-V EPRI-CELL has been validated for a wide range of problems. The code has been pre-released to utilities for demonstration testing.

Research sponsored by Electric Power Research Institute.

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Program Descriptions

4.122

U.S. DEPARTMENT OF ENERGY NUCLEAR ENERGY UNIVERSITY PROGRAM IN ROBOTICS FOR ADVANCED REACTORS

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D. K. Weber[§]

(Abstract of DOE/OR-884, July 1987)

The U.S. Department of Energy has provided support to four universities and the Oak Ridge National Laboratory in order to pursue research leading to the development and deployment of an advanced robotic system capable of performing tasks that are hazardous to humans, that generate significant occupational radiation exposure, and/or whose execution times can be reduced if performed by an automated system. The goal is to develop a generation of advanced robotic systems capable of performing surveillance, maintenance, and repair tasks in nuclear facilities and other hazardous environments.

The development of general purpose robots to perform skilled labor tasks in restricted environments is expected to have extensive payback in areas of energy systems (nuclear and fossil units), chemical plants, fire fighting, space operations, underwater activities, defense, and other hazardous activities.

Research sponsored by U.S. Department of Energy.

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4.123

AN OVERVIEW OF AI ACTIVITIES AT THE ORNL CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH

F. G. Pim C. R. Weisbin

(Abstract of paper presented at American Nuclear Society Topical Meeting on Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Snowbird, UT, August 31 - September 2, 1987)

For a few decades there had been a growing awareness and belief that automation related technologies and intelligent machines should play an increasing role in Department of Energy programs. This trend was stimulated by a number of technical studies and conferences which concluded that automation technology can, to a large degree, increase the productivity and safety in the development and operation of energy producing plants. Therefore, DOE management decided in FY 1984 to initiate a research program to satisfy perceived future requirements in the area of intelligent machine research. In support of these DOE objectives, the Oak Ridge National Laboratory (ORNL) established the Center for Engineering Systems Advanced Research (CESAR) for the purpose of addressing fundamental problems of intelligent machine technologies.

CESAR's intelligent machines research is organized along five major discipline areas: Machine Intelligence and Advanced Computing; Sensors and Vision; Human-Machine Interface; Mechanisms, Dynamics and Control; and Cross-Disciplinary Research. This paper provides an overview of CESAR's activities in each of these areas, emphasizing the research work that is foreseen to lead to short-term (2-3 years) implementation and technology transfer. Applications in a technology area selected as one of CESAR's research focus: "robotics systems for identification, navigation and manipulation in unstructured environments" will be discussed. Particular emphasis will be given to those applications

related to remote handling, remote surveillance and remote maintenance in Nuclear Plants environments.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.124

PROPOSAL FOR CONTINUED RESEARCH IN INTELLIGENT MACHINES AT THE CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH (CESAR) FOR FY 1988 TO FY 1991

C. R. Weisbin

(Abstract of ORNL/TM-10388, March 1987)

This document reviews research accomplishments achieved by the staff of the Center for Engineering Systems Advanced Research (CESAR) during the fiscal years 1984 through 1987. The manuscript also describes future CESAR objectives for the 1988-1991 planning horizon, and beyond. As much as possible, the basic research goals are derived from perceived Department of Energy (DOE) needs for increased safety, productivity, and competitiveness in the United States energy producing and consuming facilities.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.125

CESAR RESEARCH IN INTELLIGENT MACHINES

C. R. Weisbin

(Abstract of *ORNL Review*, August 1986; also paper entitled "Research Advances in Navigation and Manipulation by Autonomous Robots," presented at the Second World Conference on Robotics Research, Scottsdale, AZ, August 18-21, 1986)

There have been significant advances in autonomous robotics at the Center for Engineering Systems Advanced Research, part of the Oak Ridge National Laboratory in Oak Ridge, Tennessee. Algorithms for obstacle avoidance

have been successfully demonstrated using the HERMIES-II robot. Learning algorithms have been developed for efficient path generation utilizing information acquired during HERMIES' previous journeys. A new research manipulator (CESARM) has been designed and built which enables our modeling and control of manipulator compliance to be experimentally verified. Algorithms for mapping prececut constrained task graphs onto our new hypercube ensemble parallel computer have been successfully tested. An intelligent machine operating system (IMOS) is being based on the concepts of virtual time. Automated derivative generation allows model simplification and parameter identification. Finally, a new uncertainty analysis approach (O-Theory) was developed to allow for decision making using AI-based planning systems.

Research sponsored partially by the Human Engineering Laboratory, the U.S. Air Force Wright Aeronautical Laboratories, and U.S. DOE Office of Basic Energy Sciences.

* Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.126

INTELLIGENT-MACHINE RESEARCH AT CESAR

C. R. Weisbin

[Abstract of *AI Magazine* 8(1), 62 (1987)]

The Oak Ridge National Laboratory (ORNL) Center for Engineering Systems Advanced Research (CESAR) is a national center for multidisciplinary long-range research and development (R&D) in machine intelligence and advanced control theory. Intelligent machines (including sensor-based robots) can be viewed as artificially created operational systems capable of autonomous decision making and action. One goal of the research is autonomous remote operations in hazardous environments. This review describes highlights of CESAR research through 1986 and alludes to future plans.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.127

ROBOTICS AND INTELLIGENT SYSTEMS PROGRAM

C. R. Weisbin

(Abstract of 1987 RISP Brochure, June 1987; also oral presentation presented at the Army Strategic Defense Command Meeting, Huntsville, AL, July 10, 1987)

The Robotics and Intelligent Systems Program (RISP) at Oak Ridge National Laboratory (ORNL) builds upon the Consolidated Fuel Reprocessing Program's (CFRP's) development and demonstration of remote technology and the basic research efforts of the Center for Engineering Systems Advanced Research (CESAR). RISP is a focal point at ORNL for studies in robotics, teleoperations, and related aspects of intelligent machines, such as artificial intelligence, neural networks, and parallel computing. The program is interdisciplinary in structure, employing the expertise of scientists and engineers from several research and support divisions at ORNL. RISP conducts research for the Department of Energy (DOE), the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and other sponsors.

RISP research is intended to minimize human error through automation of repetitive, dull, and routine tasks; to minimize human risk by allowing effective remote operation in hazardous environments; and to cope effectively with emergency situations where fast response is essential. Goals of RISP research include developing an appropriate combination of teleoperation and autonomous operation with emphasis on energy-related problem areas.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.128

RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH (CESAR)

**C. R. Weisbin J. Barhen
W. R. Hamel***

(Abstract of ORNL/TM-10232, January 1987)

This document is the second issue of the Research and Development Plan for the Center for Engineering Systems Advanced Research (CESAR) at the Oak Ridge National Laboratory. The document is intended to provide a general framework for more detailed planning on an annual basis, both for DOE and for other sponsoring organizations with overlapping technical objectives in the area of intelligent machines. It will be examined each year and updated as required.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

4.129

RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH (CESAR)

**C. R. Weisbin W. R. Hamel*
J. Barhen M. C. G. Hall**

(Abstract of ORNL/TM-9732, February 1986)

During the last few years, there has been a growing awareness and belief that automation related technologies and intelligent machines should play an increasing role in Department of Energy programs. This trend was stimulated by a number of technical studies and conferences which concluded that automation technology can, to a large degree, increase the productivity and safety in the development and operation of DOE-sponsored systems. Therefore, DOE management decided to initiate a research program to extend the body of knowledge underlying current

engineering practice and satisfy perceived future requirements. In support of these DOE objectives and of requirements by other sponsoring organizations, the Oak Ridge National Laboratory has established the Center for Engineering Systems Advanced Research (CESAR) for the purpose of addressing fundamental problems of intelligent machine technologies.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

4.130

PROCEEDINGS OF A WORKSHOP: PLANNING AND SENSING FOR AUTONOMOUS NAVIGATION

Edited by:

C. R. Weisbin E. S. Howe

(Abstract of ORNL/TM-9923, January 1986)

This report represents the proceedings of the second DOE/CESAR Workshop entitled "Planning and Sensing for Autonomous Navigation." The meeting was held August 18-19, 1985 in conjunction with, and just prior to the International Joint Conference on Artificial Intelligence at the University of California, Los Angeles.

The workshop was organized around several issues developed to focus attention and clarify workshop priorities. The issues dealt with methods for "world mapping" and "discovery" in unstructured environments, approaches to real-time planning with sensor feedback, computer architectures and concurrent algorithms, sensor integration, and uncertainty representation and propagation. A series of overview papers contained herein served as background for discussion. Written summaries of group discussions were prepared during the meeting and are included in these proceedings.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

4.131

CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH

C. R. Weisbin K. McKeehan*

(Abstract of 1986 CESAR Brochure, June 1986)

The Center for Engineering Systems Advanced Research (CESAR) was established in 1983 as a national center for multidisciplinary long-range research and development in machine intelligence and advanced control theory. Intelligent machines of interest here are artificially created operational systems that are capable of autonomous decision-making and action. The initial emphasis for research is autonomous remote operations, with specific applications in unstructured dangerous environments where explosives, toxic chemicals, or radioactivity may be present or in other environments with significant risk such as coal mining or oceanographic missions. Research in multipurpose plant management and maintenance will be phased into the CESAR program in the near future. Research objectives include modeling the dynamics of flexible structures, developing software for real-time planning with sensor feedback, formulating a learning theory for enhanced knowledge acquisition and interpretation, determining optimal concurrent algorithms for implementation on advanced parallel computers, generating automated sensitivity analysis methods for model simplification and parameter identification, and formulating and testing comprehensive uncertainty analysis methodology.

Research sponsored by U.S. DOE Office of Basic Energy Sciences.

*Information Services Division.

Section 5

ENGINEERING PHYSICS INFORMATION CENTERS

5.0. INTRODUCTION

**B. F. Maskewitz
R. W. Roussin**

Information analysis and data management, important activities of the division since its inception, comprise a significant fraction of the division's program. Under the management umbrella of Engineering Physics Information Centers (EPIC), we operated two specialized centers during the reporting period, July 1, 1985 — September 30, 1987. The Radiation Shielding Information Center (RSIC), founded in FY 1963, has served the international scientific community as a technical institute for shielding design and analysis. The Technical Data Management Center (TDMC) was founded in FY 1976 to perform various tasks in support of Nuclear Regulatory Commission (NRC) programs in technical data management and computer code development, standardization and maintenance. TDMC was phased out during the second quarter of FY 1987.

RSIC and TDMC are described in greater detail as follows.

Radiation Shielding Information Center (RSIC)

RSIC observed its 25th year in operation during this reporting period. It continues to be widely used as attested by current user statistics. Usage reported at the end of FY 1987 showed that the total number of requests processed during the year (3782) exceeded those last reported (FY 1984; 3408) by 11%. The report indicates that the individual user is requesting more products and/or services; activities required to fill the requests increased by 37% (12,881 vs 9423). The pattern of usage during the reporting period is interesting and may reflect changes in the industry. User statistics for FY 1985 showed a change from the prior year of -8%, a gain of +2% in FY 1986, and a larger gain in FY 1987 of +18%. The increased usage is largely attributed to waste management and defense-related programs.

RSIC's quarter century efforts were also recognized by the American Nuclear Society through its 1987 Radiation Protection and Shielding Division Technical Service Award, the first presentation to an institution. RSIC was formally recognized for its "twenty-five years of dedicated support and service to the international radiation protection and shielding community."

Established to promote the exchange of shielding technology, RSIC acts as a resource base for both government and civilian agencies in the United States and in foreign countries and performs such diverse functions as providing bibliographic information; testing, assembling, and distributing computer codes; preparing, testing and distributing multigroup cross-section libraries, both fine-group and broad-group; collecting and distributing other types of data bases; holding seminars to educate the shielding community on particular techniques, especially computer-based techniques for solving radiation transport or nuclear data problems; helping to establish shielding benchmark problems and shielding standards; and generally providing problem assistance to requesters.

The RSIC scope includes the physics of interaction of radiation with matter; radiation production, protection, and transport; radiation detectors and measurements; engineering design techniques; shielding materials properties; computer codes useful in research and design; and nuclear data compilations. The goals of RSIC are to function as a technical institute to provide information (bibliographic and other data, computer codes, technical advice) upon request; collect, evaluate, enrich, distill, and repackage information to extend the state of the art, bringing into the public domain technology more usable and more valuable than the sum of the input; and to initiate and effect research and development in appropriate areas of need.

During this reporting period work has continued in the development of fine- and broad-group cross-section data libraries. The 174 neutron, 38 gamma-ray group VITAMIN-E general-purpose cross-section library based on ENDF/B-V now contains 94 materials. It has been used with success for fusion neutronics, fast reactor core and shielding applications, and various other radiation transport calculations within the division and externally. The generation of multigroup data for some of ENDF/B-V evaluations, Revision 2, has also been completed and the resulting data was recently released as part of VITAMIN-E.

RSIC has continued to participate in the work of the Cross Section Evaluation Working Group (CSEWG), with the Methods and Formats Subcommittee chaired by the RSIC director. Other staff members are actively involved with the ANS in developing radiation protection and shielding standards and standards for scientific computer programming and its documentation.

In the area of computing technology, RSIC now makes available 761 computer code packages and 129 data packages. The RSIC Newsletter is currently mailed monthly to 1467 people. A total of 221 persons (123 foreign, 98 domestic) came during the reporting period for an orientation visit and/or to use the center's facilities, an average of 74 persons/year.

In terms of reciprocity in international information exchange, a significant percentage of all incoming computing technology (codes and data) comes from foreign contributors, with Japan and France continuing in the lead. Much of the new technology is of domestic interest.

The RSIC computer-based information system (SARIS), containing more than 23,242 literature references, is used in support of internal research activities and user services. Seven consecutive indexed bibliographies have been published and data files have been constructed in preparation for publication of the eighth in the series. SARIS, formerly accessible nationally on the now-defunct DOE RECON system, is currently accessible for a search on demand service.

RSIC interacts daily with, and continues to have the support of its user community. Participants contributed their publications and 230 separate transmissions of technology as follows: 106 new computer codes and data libraries; 20 replacements of existing code/data packages with newly-frozen versions; 39 new hardware versions or other extensions to existing code/data packages; 33 updates to improve existing code/data packages; and 32 corrections to fix errors in existing code/data packages.

Announcement of availability was made for 248 transportable, tested packages of new or revised computer code systems and data libraries, including contributions received in the previous fiscal year. It should be noted that the same evaluation, computer testing, and packaging is followed for updates to existing code packages as for new technology.

Technical Data Management Center

TDMC was established in July 1976 to serve NRC programs with goals and priorities determined by an advisory committee of NRC technical staff members chaired by the contract monitor within the Division of Technical Information and Document Control of the NRC Office of Administration. Its primary purpose was to support NRC programs by assisting in verification, validation, documentation, and standardization of computing technology (including codes and other technical data) used in the licensing and regulatory processes. Progress was made in all tasks assigned by the contract monitor in FY 1985-1986. Several code systems and newly developed utility routines were implemented on NRC computers, documented, and made generally available.

A subtask included calculations to generate data for the proposed ANS-6.4.3 standard, "Gamma-Ray Attenuation Coefficients and Buildup Factors for Engineering Materials," a collaboration with the ANS-6 Standards Subcommittee. The working group has selected data sets from NBS and from Japan with other data serving as validation. The G-P buildup factor coefficients were determined in Japan. The G-P technology has been implemented in the QAD-CGGP code system which is available from RSIC as is 1985 data base as a data library. Revised data is expected from Japan before the end of December. A report of the compilation effort, including discussion of the technical issues and the draft standard, has been written. The draft is ready for review by the working group with publication expected early in 1988 when it enters the ANSI approval process.

The decision was made during NRC reorganization early in FY 1987 to terminate the TDMC program. Closeout activities will be completed by the end of FY 1988.

Radiation Transport Developments

5.1

DISCRETE ANGLE BIASING IN MONTE CARLO RADIATION TRANSPORT

S. N. Cramer

[Abstract of *Nucl. Sci. Eng.* (in press)]

An angular biasing procedure is presented for use in Monte Carlo radiation transport with discretized scattering angle data. As in more general studies, the method is shown to reduce statistical weight fluctuations when it is combined with the exponential transformation. This discrete data application has a simple analytic form which is problem independent. The results from a sample problem illustrate the variance reduction and efficiency characteristics of the combined biasing procedures, and a large neutron and gamma ray integral experiment is also calculated. A proposal is given for the possible automatic generation of the biasing parameter p and the preferential direction Ω_0 used in the combined biasing schemes.

Research sponsored by Defense Nuclear Agency.

5.2

NEW BUILDUP FACTOR DATA FOR POINT KERNEL CALCULATIONS

D. K. Trubey Y. Harima*

[Abstract of *Trans. Am. Nucl. Soc.* 53, 416 (1986); also paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 2, p. 503 (1987)]

An American Nuclear Society Standards Committee Working Group, identified as ANS-6.4.3, is developing a set of evaluated gamma-ray isotropic point-source buildup factors and attenuation coefficients for a standard reference data base. As a first step, a largely unpublished set of buildup factors calculated with the moments method has been evaluated by recalculating key values with Monte Carlo, integral transport, and discrete ordinates methods. Attention is being given to frequently neglected processes such as bremsstrahlung and the effect of introducing a tissue phantom behind the shield. The proposed standard contains data for a source energy range from 15 keV to 15 MeV and for approximately 19 elements and 3 mixtures (water, air, and concrete). The data will also be represented as coefficients for the G-P fitting function. The 1985 data base was released as part of the CCC-493B/QAD-CGGP code package available from the Radiation Shielding Information Center (RSIC).

Research sponsored by U.S. DOE and U.S. Nuclear Regulatory Commission.
*Tokyo Institute of Technology, Tokyo, Japan.

5.3

RADIATION SHIELDING AND PROTECTION

R. W. Rossini D. K. Trubey

(Abstract of a chapter in *Encyclopedia of Physical Science and Technology*, Vol. 11, pp. 596-632, Robert Meyers, Editor-in-Chief, Academic Press, Inc., Orlando, FL, 1987)

Radiation shielding allows mankind to exploit a variety of uses of nuclear energy. It is used to protect workers, the general public, and radiation sensitive equipment from sources of radiation, both natural and manmade. Society's increasing use of radiation-producing equipment and the increasingly stringent radiation regulations mandate effective shielding.

Radiation protection is concerned with both internal sources (ingested or inhaled radioactivity) and external sources. These external sources vary from nuclear reactors and other equipment used in the nuclear power industry to hospital accelerators to released radioactivity from accidental discharge. The shielding of external sources is concerned primarily with penetrating radiation, mainly neutrons, gamma rays, and x rays since electrically charged radia-

tion such as beta and alpha rays do not present a significant shielding problem unless their energies are extremely high. Particles of high energy are found near accelerators and in space, but this topic will not be discussed in this article.

Shielding may be considered a branch of nuclear engineering. It may be defined as the branch of engineering, including the underlying

research, concerned with the design and analysis of shields. The shielding engineer is concerned with the selection of materials and specification of their dimensions to reduce the radiation dose rate to acceptable levels, given particular sources.

Research sponsored by U.S. DOE Office of Fusion Energy.

Radiation Transport Studies

5.4

GAMMA RAY TRANSPORT IN SHIELD-TISSUE COMPOSITE SYSTEM AND THE BUILDUP FACTOR IMPLICATIONS

D. V. Gopinath* K. V. Subbaiah*
D. K. Trubey

[Abstract of *Nucl. Sci. Eng.* (in press)]

The paper presents transport computations in shield-tissue composite systems. It is observed that the scattered gamma-ray spectra at the interface, which are governed by the reflectivities of different media, are significantly different from those of an infinite medium. The interface effects also extend back into the shield medium, the extent depending on the atomic number of the medium and energy of the source photons. The implications of these differences on the dose distribution and buildup factors in the shield-tissue system are significant. These studies show that the infinite-medium buildup factors are quite inadequate to compute the maximum dose in the tissue following a shield in many cases. Appropriate correction factors are given.

The singular behavior of the spectrum due to source photons of energy close to but above the K edge of the medium is highlighted.

Research sponsored by Nuclear Regulatory Commission.

*Indira Gandhi Centre for Atomic Research, Kalpakkam, India.

5.5

EFFECTS OF INCOHERENT AND COHERENT SCATTERING ON THE EXPOSURE BUILDUP FACTORS OF LOW-ENERGY GAMMA RAYS

H. Hirayama* D. K. Trubey

[Abstract of *Nucl. Sci. Eng.* (in press)]

The effects of including incoherent and coherent scattering in a calculation of the exposure buildup factors for plane normal gamma-ray sources have been investigated by using an electron gamma-ray shower Monte Carlo code, EGS4, for water, iron, and lead in the 40 to 200 keV range. The "true" buildup factors and "pseudo" buildup factors for practical uses are defined to clarify the effects of bound-electron Compton (incoherent) and coherent scattering and are tabulated for penetration depths up to 10 mfp.

The pseudo buildup factor is larger by including incoherent scattering and decreases by including coherent scattering. The degree of each effect varies with the atomic number of the material. The effect of incoherent scattering is large for materials of small atomic number, and the effect of coherent scattering is large for materials of large atomic number.

Research sponsored by U.S. Nuclear Regulatory Commission Office of Information Resource Management.

*National Laboratory for High Energy Physics, Japan.

5.6

ASSESSMENT OF SHIELDING ANALYSIS METHODS, CODES, AND DATA FOR SPENT FUEL TRANSPORT/STORAGE APPLICATIONS

C. V. Parks* B. L. Broadhead*
S. N. Cramer J. C. Gauthey
O. W. Hermann* B. L. Kirk
R. W. Roussin J. S. Tang*

[Abstract of ORNL/CSD/TM-246 (in press)]

This report provides a preliminary assessment of the computational tools and existing methods used to obtain radiation dose rates from shielded spent fuel and high-level radioactive waste. Particular emphasis is placed on analysis tools and techniques applicable to casks designed for the transport or storage of spent fuel or high-level waste. Applications to cask transport, storage, and facility handling are considered. The report reviews the analytic techniques for generating appropriate radiation sources, evaluating the radiation transport through the shield, and calculating the dose at a desired point or surface exterior to the shield. Discrete ordinates, Monte Carlo and point kernel methods for evaluating radiation transport are each reviewed.

Also, a literature survey was employed to select a cadre of codes and data libraries to be reviewed. The selection process was based on specific criteria presented in the report. Separate summaries were written for several codes (or family of codes) providing information on the method of solution, limitations and advantages, availability, data access, ease of use, and known accuracy. For each data library, the summary covers the source of the data, its applicability, and known verification efforts.

Finally, the report discusses the overall status of spent fuel shielding analysis techniques and attempts to note and justify areas where improvement is needed. The report notes the advantages and limitations of several analysis procedures and illustrates the importance of using adequate

cross-section data sets. More work to provide verification of the computer programs and associated data is recommended.

Research sponsored by the Computing and Telecommunications Division.

*Computing and Telecommunications Division.

5.7

INTERCOMPARISON OF CROSS-SECTION LIBRARIES USED FOR SPENT FUEL CASK SHIELDING ANALYSIS

C. V. Parks* B. L. Broadhead*
R. W. Roussin J. C. Gauthey
S. N. Cramer B. L. Kirk

[Abstract of paper presented at the American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vol. 2, p. 559 (1987)]

A study has been made to compare the surface dose rates obtained from one-dimensional analyses of an iron-shielded spent fuel cask using a variety of available broad- and fine-group cross-section libraries. MCNP analyses using point cross-section data were also performed. Alternate versions of the broad-group libraries were developed to study the effect of resonance self-shielding, group structure, weighting spectrum, and data origin (ENDF/B-IV versus ENDF/B-V). The results presented indicated significant discrepancies in the final doses. The discrepancies are evidently due to inadequate resonance self-shielding treatment and improper weighting spectra for the fine-group collapse. Discrepancies between the fine-group results and the point data results are also observed.

Research sponsored by U.S. Department of Energy.

*Computing and Telecommunications Division.

Information Analysis Center Activities

5.8

NUCLEAR REGULATORY COMMISSION PROGRAMS SUPPORTED BY THE TECHNOLOGY RESOURCES OF THE ENGINEERING PHYSICS INFORMATION CENTERS

N. A. Hatmaker R. W. Roussin
J. E. White

(Abstract of poster session presented at the 14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 27-31, 1986)

The Engineering Physics Information Centers (EPIC) at Oak Ridge National Laboratory have two activities which support NRC programs, the Radiation Shielding Information Center (RSIC) and the Technical Data Management Center (TDMC). The older of the two, RSIC, was established in 1963 as an Information Analysis Center in the general field of radiation shielding, transport, and protection. It has multiple agency funding to acquire, evaluate, organize, and distribute information (including computing technology and numerical data) relevant to its field. The TDMC was established in 1978 to perform work for NRC in fields not related to RSIC's subject coverage and to perform tasks beyond the normal level of activity for RSIC. The two centers share administrative functions, physical premises, specialists' skills, and computing resources. The NRC/ADM/TIDC monitors the cosponsorship of RSIC for coverage of agency-wide interests and plans, directs, and coordinates the work of the TDMC, including the establishment of TDMC as the agency-wide repository for packaged computer-related technical information products.

Research sponsored by U.S. Nuclear Regulatory Commission.

5.9

NUCLEAR INDUSTRY QUALITY, PRODUCTIVITY, AND INNOVATION FROM THE PERSPECTIVE OF AN INTERNATIONAL INFORMATION CENTER

B. F. Maskewitz

(Abstract of paper presented at the 1987 WATtec Conference on Perspectives in Global Competitiveness, Quality, Productivity, and Innovation, Knoxville, TN, February 17-20, 1987)

In the aftermath of the Chernobyl accident, the prevailing attention of the international nuclear community is focused on the safe operation of the world's nuclear power plants. QA, man-machine interaction, early warning systems, and effectively organized crisis centers are increasingly receiving attention. At the same time, the nations which lack natural energy resources are increasingly dependent on the nuclear option, and the productivity of their nuclear power plants is of great importance.

This paper examines the USA situation in general. Then, through the unique "window" furnished by an international information center, briefly reviews quality, productivity, and innovation aspects of the nuclear industry in several foreign countries including China (PRC), the Soviet Union, Czechoslovakia, and Hungary.

Research sponsored by U.S. Department of Energy.

5.10

THE ANATOMY OF INTEGRATED DATA MANAGEMENT

B. F. Maskewitz

(Abstract of oral presentation given at the 191st National Meeting of the American Chemical Society, Division of Industrial and Engineering Chemistry, Separations Science and Technology Subdivision, New York, NY, April 13-18, 1986)

Separations scientists are not immune from the information explosion which inundates the international research community in today's

rapidly changing scientific environment. The individual scientist cannot work in a vacuum without continually "reinventing the wheel." Integrated data management through cooperation and collaboration is an imperative for the individual who needs to maintain cognizance of the knowledge base of the rapidly advancing state of the art. An analysis is made of the indicators for integrated data management. Guidelines are suggested for establishing a focal point for a collaborative effort within a specialized scientific field. Examples are cited of successful centers established through the efforts of specialists within a technical society which began with society sponsorship only and later secured a sound financial base from other sources. The anatomy of integrated data management is reviewed for a national repository and disseminating center for scientific computer codes, a national clearinghouse for collaborative evaluation of experimental and processed numeric data, an information center and clearinghouse for biomedical computing technology, and an international technical institute. Each of these began as an expression of need from a specialized technical research community within a professional/technical society.

Research sponsored jointly by U.S. Department of Energy, U.S. Nuclear Regulatory Commission, and Defense Nuclear Agency.

5.11

THE RADIATION SHIELDING INFORMATION CENTER — AN INTERNATIONAL TECHNOLOGY RESOURCE

B. F. Maskewitz

(Abstract of *NCC News*, August 1986)

The Radiation Shielding Information Center (RSIC) is a technical institute serving the international shielding community. It acquires, selects, stores, retrieves, evaluates, analyzes, synthesizes, and disseminates information on radiation production, radiation protection, and radiation shielding, and ionizing radiation transport.

During this fiscal year RSIC observes its 23rd year in operation. Established to promote the exchange of shielding technology, it acts as a resource base for both government and civilian agencies in the United States and in foreign countries and performs such diverse functions as providing bibliographic information; testing, assembling, and distributing computer codes; preparing, testing, and distributing multigroup cross-section libraries, both fine-group and broad-group; collecting and distribution other types of data bases; holding seminars to educate the shielding community on particular techniques, especially computer-based techniques for solving radiation transport or nuclear data problems; helping to establish shielding benchmark problems and shielding standards; and generally providing problem assistance to requesters.

Research sponsored by U.S. Department of Energy.

5.12

THE RADIATION SHIELDING INFORMATION CENTER (RSIC): AN OVERVIEW

B. F. Maskewitz R. W. Roussin
N. A. Hatmaker

(Abstract of oral presentation given at the ORAU Workshop on Passive Nuclear Reactors in the Far East, Oak Ridge National Laboratory, Oak Ridge, TN, August 16, 1985)

A brief review of the several classes of technical information repositories (documents, data, computer codes) and of clearinghouses and data bases preceded the definition and discussion of the operating philosophy of the integrated information analysis center concept with the Radiation Shielding Information Center (RSIC) as a prime example. The overall RSIC objective to "acquire, evaluate, organize, and distribute information (literature, numeric data, and computer codes) in support of national and international programmatic needs" was reviewed in detail. RSIC's technical areas (physics of interaction of radiation with matter, radiation production, transport, shielding and protection, radiation detectors and measurement, engineering design techniques,

shielding material properties, computer code, and data compilations) were of strong interest to the group (mostly Japanese), as they had just completed a study of passive nuclear reactors. International exchange of information, with emphasis on the necessity for reciprocity, was stressed.

Research sponsored by U.S. DOE Office of Nuclear Energy and Office of Fusion Energy.

5.13

APPROXIMATE CALCULATIONAL TECHNIQUES FOR RADIATION PROTECTION APPLICATIONS (COLLECTION OF PAPERS PRESENTED AT THE NOVEMBER 1985 AMERICAN NUCLEAR SOCIETY MEETING)

A. F. Rice R. W. Remain

[Abstract of ORNL/RSIC-48 (ANS/SD-86/17), September 1986]

This report documents two sessions on "Approximate Calculational Techniques for Radiation Protection Applications," held during the American Nuclear Society Winter Meeting in San Francisco, California, November 1985. Interest generated by these sessions has resulted

in the present publication consisting of ten of the thirteen papers presented at the meeting.

Although radiation protection principles are, on the whole, well understood and a whole series of computer codes exist for their solution, it is felt that there is a need for practical, approximate techniques to be used by the practicing nuclear engineer for a variety of applications. The importance of such "qualified" approaches varies from being necessary, when time does not permit detailed computer analyses and your boss does not trust your "gut-feeling," to being useful in perturbation analyses and to quickly "benchmark" a new computer code or application.

Within the context of approximate techniques, the papers presented cover a broad overview of specific problems; for example, skyshine and penetration analysis, with applications extending from general nuclear reactor design to spent fuel storage and fusion.

It is our intent to see this publication as the first of a series of sessions and publications directed towards the qualification of a broad spectrum of radiation protection approximation techniques for a wide variety of applications.

Research sponsored by the Radiation Protection and Shielding Division of the American Nuclear Society.

Transfer of Computing Technology

5.14

UPDATE — A FORTRAN 77 SOURCE FILE MANIPULATOR (ADAPTED FOR THE DATA GENERAL MV SERIES ECLIPSE COMPUTERS UNDER AOS/VS)

B. L. Kirk

[Abstract of ORNL/NUREG/TDMC-4 (NUREG/CR-4478) (in press)]

The primary purpose of UPDATE, which originated at Lawrence Berkeley Laboratory, is to provide a capability for maintaining source files.

This portable version, which has the same name and function as the original CDC utility program, serves as a file manager and can be a valuable tool in computer code development work. Written in FORTRAN 77, its general function is to manipulate source files by allowing the user to modify the source code through a series of commands called directives. The source file with UPDATE directives is initially copied to another file called a program library. Changes are then made to the program library. From this program library is extracted the 'compile-ready' file, that is the final input to a FORTRAN 77 compiler.

Research sponsored by U.S. Nuclear Regulatory Commission.

5.15

**THE INTEGRATED TIGER SERIES
OF ELECTRON/PHOTON MONTE
CARLO TRANSPORT CODES:
A USERS' GUIDE FOR USE
ON IBM MAINFRAMES**

B. L. Kirk

(Abstract of ORNL/TM-9767, December 1985)

The ITS (Integrated Tiger Series) Monte Carlo code package developed at Sandia National Laboratories and distributed as CCC-467/ITS by the Radiation Shielding Information Center (RSIC) at Oak Ridge National Laboratory (ORNL) consists of eight codes — the standard codes, TIGER, CYLTRAN, ACCEPT; the P-codes, TIGERP, CYLTRANP, ACCEPTP; and the M-codes ACCEPTM, CYLTRANM. The codes have been adapted to run on the IBM 3081, VAX 11/780, CDC-7600, and CRAY 1 with the use of the update emulator UPEML. This manual should serve as a guide to a user running the codes on IBM computers having 370 architecture. The cases listed were tested on the IBM 3033, under the MVS operating system using the VS FORTRAN Level 1.3.1 compiler.

Research sponsored by U.S. Department of Energy and Defense Nuclear Agency.

5.16

**INDUCTIVE TIME SERIES
MODELING PROGRAM**

E. L. Kirk B. W. Rust*

(Abstract of ORNL/TM-7534, October 1985)

A number of features that comprise environmental time series share a common mathematical behavior. Analysis of the Mauna Loa carbon dioxide record and other time series is aimed at constructing mathematical functions which describe as many major features of the data as possible. A trend function is fit to the data, removed, and the resulting residuals analyzed for any significant behavior. This is repeated until the residuals are driven to white noise. In the following discussion, the concept of trend will include cyclic components.

The mathematical tools and program packages used are VARPRO for the least squares fit, and a modified version of our spectral analysis program for spectrum and noise analysis.

The program is written in FORTRAN. All computations are done in double precision, except for the plotting calls where the DISSPLA package is used. The core requirement varies between 600 K and 700 K. The program is implemented on the IBM 360/370. Currently, the program can analyze up to five different time series where each series contains no more than 300 points.

Research sponsored jointly by the National Science Foundation's Ecosystem Studies Program and by U.S. DOE Office of Energy Research, Carbon Dioxide Research Division.

*National Bureau of Standards, Washington, DC.

APPENDICES

SCIENTIFIC AND PROFESSIONAL ACTIVITIES

July 1, 1985 — September 30, 1987

V. Alexiades

Invited lectures

- "Void Formation," Mathematics Department, University of Heidelberg, Heidelberg, West Germany, June 1987.
- "Equilibrium Size of a Nucleus Forming in Supercooled Liquid," International Conference on Free Boundary Problems, Irsee/Bavaria, West Germany, June 1987.
- "Void Formation in Solidification," EQUADIFF 87 Conference on Differential Equations, Xanthi, Greece.

Associate Professor

- Mathematics Department, University of Tennessee, Knoxville, TN.

Award

- UTK-ORNL Science Alliance Research Incentive Award, 1986 and 1987.

Reviewer

- *Mathematics Reviews*

Referee

- *Applicable Analysis*
- *SIAM Journal of Mathematical Analysis*
- *Nonlinear Analysis*
- *International Journal of Heat and Mass Transfer*
- *ASME Journal of Heat Transfer*

R. G. Alsmiller, Jr.

Member

- DOE Panel for the Review of the Report of the SSC Environmental Radiation Shielding Task Force, J. D. Jackson, Editor.
- National Committee on Radiological Protection, Scientific Committee 52 on Conceptual Basis of the Calculations of Dose Distributions.

Chairman

- Department of Energy Advisory Panel on Accelerator Radiation Safety for the Review of TEVATRON I and TEVATRON II at the Fermi National Accelerator Laboratory.
- Department of Energy Advisory Panel on Accelerator Radiation Safety for the Review of the Stanford Linear Collider at the Stanford Linear Accelerator Center.

Invited paper

- "Modifications of the High-Energy Transport Code (HETC) and Comparisons with Experimental Results," (with F. S. Alsmiller, T. A. Gabriel, and O. W. Hermann) ANS Topical Conference on Theory and Practice in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987.

Award

- Cited for contributions to the Space Station Phase II Design Effort by Martin Marietta Michoud Division.

Referee

- *Nuclear Science and Engineering*
- *Physics in Medicine and Biology*

C. B. Anthony**Award**

- 1987 ANS RP&S Division Technical Service Award.

Y. Y. Azmy**Chairman**

- Reactor Physics Methods Session, 1987 American Nuclear Society Annual Summer Meeting, Dallas, TX, June 1987.

Invited paper

- "A Numerical Parametric Analysis of Nonlinear Phenomena in the Confined Benard Problem," presented at the 1986 ANS Winter Meeting, Washington, DC, November 1986.

Award

- 1986 ANS Mark Mills Award

Referee

- *Nuclear Science and Engineering*

J. L. Bartley**Invited paper**

- "System Driver, Reading Routines, and Subroutine Library," RSIC/TDMC Workshop on the SCALE Computational System, Oak Ridge, TN, April 15-18, 1986.

Award

- 1987 ANS RP&S Division Technical Service Award.

J. J. Beauchamp**Member**

- Engineering Physics and Mathematics Division Employee Communication Survey Advisory Group.
- Engineering Physics and Mathematics Division Ambience Committee.

Co-Chairman

- Mathematics Judging Team for the 39th International Science and Engineering Fair.

Invited paper

- "Algorithms for Bayesian Variable Selection in Regression," (with T. J. Mitchell) 18th Symposium on the Interface of Computer Science and Statistics, Fort Collins, CO, March 20–21, 1986.

Instructor

- Oak Ridge Graduate School of Biomedical Sciences, University of Tennessee, Knoxville, TN.

Referee

- *Environmental International*
- *Communications in Statistics, Simulation and Computation*
- *Chemometrics and Intelligent Laboratory Systems*

K. O. Bowman**Member**

- Committee on Section T — Information, Computing, and Communication, American Association for the Advancement of Science.
- Committee of Representatives to the AAAS, American Statistical Association.
- Committee of Representatives to the AAAS, committee of Presidents of Statistical Societies.
- Committee of History of Statistics, Slide presentation of Sesquicentennial, American Statistical Association
- Advisory Committee on Equal Opportunities in Science and Engineering, National Science Foundation.
- Program Committee, First International Association for Statistical Computing (IASC) World Conference on Computational Statistics and Data Analysis, Shizuoka, Japan, September 17–19, 1987.
- Advisory Board, *Journal of Statistical Computation and Simulation*.
- International Editorial Board, *Communications in Statistics*.
- Advisory Committee, Educational Testing Center.

Chairman

- Subcommittee on Disabled, Equal Opportunities in Science and Engineering, National Science Foundation.
- Coordinating Committee on Equal Opportunities in Statistics, American Statistical Association.

Invited lectures/papers

- "Statistical Inference — Computer Oriented Algorithmic Approach," First IASC World Conference on Computational Statistics and Data Analysis, Shizuoka, Japan, September 17–19, 1987.
- "Small Sample Properties of Statistics — Computer Algorithmic Approach," Southern Regional Education Board/Southern Regional Committee on Statistics Summer Research Conference, Gatlinburg, TN, June 14–19, 1987.
- "Small Sample Properties of Statistics — Computer Algorithmic Approach," Institute of Statistical Mathematics, Tokyo, Japan; Union of Japanese Scientist and Engineers, Tokyo, Japan; and Keio University, Kanagawa, Japan, November 10–21, 1986.

- "Special Concerns: Research Statistics," Research Meeting on Science and Mathematics for Students with Disabilities, AAAS Office of Opportunities in Science Linkage Project, Washington, DC, February 11, 1986.
- "New Directions for Women, Minorities, and Disabled," Report from the National Science Foundation Committee on Equal Opportunities in Science and Technology, AWIS Oak Ridge Chapter, Oak Ridge, TN, May 19, 1986.

Lecturer

- Visiting Lecture Program, Committee of President of Statistical Societies (COPSS).

Co-Organizer

- Symposium on Trends in Supercomputers: Architecture and Applications, AAAS Annual Meeting, Philadelphia, PA, May 1986.

Organizer

- Invited Session, ASA Annual Meeting, San Francisco, CA, August 1987.

Contributing editor

- *Current Index to Statistics*.

Reviewer

- *Science*, American Association for the Advancement of Science.
- Research Proposal, National Science Foundation.

Referee

- *Communications in Statistics*
- *Journal of Statistical Computation and Simulation*
- *Biometrics*
- *Pakistan Journal of Statistics*

Award

- Fellow, Institute of Mathematical Statistics, 1987.

Thesis

- "Small Sample Properties of Statistics — computer Algorithmic Approach," Doctor or Engineering Degree, University of Tokyo, Tokyo, Japan, 1987.

B. L. Burks

Invited lectures

- "Autonomous Robots at ORNL," Oliver Springs Elementary School Career Day, April 28, 1987.
- "A Demonstration of Autonomous Navigation, Exploration, and Recognition Using the HERMIES-IIIB Robot," DOE /ANL training course on the Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities, August 18, 1987.
- "A Demonstration of Autonomous Navigation, Exploration, and Machine Vision Using the HERMIES-IIIB Robot," Great Lakes College Association, Alliance of Colleges in the Midwest (GLCA/ACM) Oak Ridge Science Semester Seminar," September 30, 1987.

D. G. Cacuci**Member**

- Department of Energy Working Group on Reassessment of A-Bomb Dosimetry.

General Chairman

- 1987 Topical Meeting on Theory and Practices in Radiation Protection and Shielding.

Editor

- *Nuclear Science and Engineering*.

Professor (Part-time)

- Department of Nuclear Engineering, University of Tennessee.

Lecturer

- ISPRA Course on Data Uncertainties, Sensitivities, Consistency, and Adjustment, Ispra, Italy, 1986.

Invited lectures/seminars

- Hebrew University, Jerusalem, Israel, 1986.
- Ben Gurion University, Beer Sheva, Israel, 1986.
- National Academy of Sciences, 1986 and 1987.
- California Institute of Technology, 1986.
- University of California at Santa Barbara, 1986 and 1987.
- University of Arizona, 1987.
- Georgia Institute of Technology, 1986.

Awards

- Fellow, American Nuclear Society.
- Martin Marietta Energy System's Publications Award for Excellence, 1987.
- Best Paper Award, ANS, RPD, 1986.

R. J. Carter**Chairman**

- Exhibits Committee, ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems.

Member

- Technical Program Committee, ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems.
- Air Force Tiger Team on Hazardous Materials/Waste Training.

C. P. Coker**Award**

- 1987 ANS RP&S Division Technical Service Award.

S. N. Cramer**Award**

- 1987 ANS RP&S Division Technical Service Award.

G. de Saussure**Member**

- Program Committee on Anticipated and Abnormal Transients in Nuclear Power Plants, Atlanta, GA, April 12–15, 1987.
- Organizing Committee for the Topical Conference "Fifty Years with Nuclear Fission," National Bureau of Standards, Washington, DC, April 26–28, 1989.

Assistant Technical Chairman

- ANS/ENS International Conference, October 30 – November 4, 1988.

Honorary Professor

- Nuclear Engineering Department, University of Tennessee.

Referee

- *Nuclear Science and Engineering*
- *The Physical Review*
- *Nuclear Safety*

J. K. Dickens**Member**

- American Nuclear Standards Working Group 5.1, Decay Heat Standard.
- American Nuclear Standards Working Group 5.2, Fission Product Yields.

Correspondent

- Designated by IAEA Working Group on Fission Product Nuclear Data as correspondent on worldwide experimental measurements of fission product decay heat (1977–continuing).

Invited paper

- "Current Status of Decay Heat Measurements, Evaluations, and Needs," ANS Topical Meeting on Reactor Physics and Safety, Saratoga Springs, NY, September 17–19, 1986; Proc. NUREG/CP-0080, Vol. 2, p. 671 (1986).

Invited lectures

- "Neutron and Gamma-Ray Fluences in a Tokamak Environment Due to a Point Source Simulating D-T Fusion Plasma Neutron Production," Nuclear Engineering Department, Rensselaer Polytechnic Institute, Troy, NY, September 15, 1986.
- "Reactor Safety and the Status of Commercial Nuclear Energy in the U.S.," Public Forum presentation, Concord College, Athens, WV, April 8, 1987.
- "Review of New Integral Determinations of Decay Heat," Specialists' Meeting on Data for Decay Heat Predictions, Studsvik, Sweden, September 7–10, 1987.

Referee

- *Nuclear Science and Engineering*
- *The Physical Review*
- Department of Energy Small Business Proposal

F. C. Difilippo**Member**

- Committee on the Physics of Criticality Safety (DOE).
- TSF Subcommittee Reactor Operations Review Committee (ORNL).
- Goal Committee, Reactor Physics Division, American Nuclear Society.

Invited papers

- "A Preliminary Reactor Design for the Center for Neutron Research," Workshop on an Advanced Steady State Neutron Facility, National Bureau of Standards, December 1985.
- "An Intense Steady State Neutron Source — The CNR Reactor," ANS Topical Meeting on Reactor Physics and Safety, Saratoga Springs, NY, September 17-19, 1986; Proc. NUREG/CP-0080, Vol. 2, p. 792 (1986).

Invited talk

- "Interpretation of Spatial Effects in Reactivity Measurement with the 252Cf Source Noise Method," USDOE/PNC (Japan) Criticality Program, Oak Ridge, TN, September 1986.

Honorary Professor

- Nuclear Engineering Department, University of Tennessee, Knoxville, TN.

Listed

- International Directory of Nuclear Criticality Safety Personnel.

Referee

- *Nuclear Science and Engineering*

T. H. Dunigan**Award**

- Martin Marietta Energy Systems Technical Achievement Award.

W. W. Engle, Jr.**Chairman**

- Registration Committee, ANS Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987.
- Membership Committee, Radiation Protection and Shielding Division, American Nuclear Society

Y. H. Etheridge**Member**

- Institute for Electrical and Electronic Engineering (IEEE).
- American Mathematical Society.
- Association for Computing Machinery.

E. L. Frome**Member**

- American Statistical Association Committee on Statistics and the Environment.
- Statistics Test Panel for Data Management Systems in Genetic Toxicology Sponsored by U.S. EPA.
- Organizing Committee for the American Statistical Association Conference on Radiation and Health (Chairman in 1985).
- ORAU/University of North Carolina Research Planning Group for DOE Health and Mortality Studies.

Associate professor

- Department of Biostatistics, University of North Carolina, Chapel Hill, NC.

Associate editor

- *The American Statistician*, 1983–present.

Invited papers

- "Statistical Analysis of Cytogenetic Dose-Response Curves," Sixth Annual ASA Conference on Radiation and Health, Berkeley Springs, WV, July 1986.

Referee

- *The American Journal of Epidemiology*
- *Statistics in Medicine*
- *The American Statistician*
- *Water Resources Research*

C. Y. Fu**Member**

- Evaluation Methods Subcommittee, Cross Section Evaluation Working Group (CSEWG).
- Standards Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Invited papers nominated for awards

- "Evaluation and Testing of Double Differential $Fe(n,xn)$ Cross Sections," nominated by the Radiation Protection and Shielding Division of the American Nuclear Society for Best Paper Award, 1986 Winter Meeting, Washington, DC, November 1986.
- "Simplified Spin Cutoff Factors of Particle-Hole Level Densities in Precompound Nuclear Theory," nominated by R. W. Peelle for the 1987 Martin Marietta Best Paper Award.

Referee

- *Nuclear Science and Engineering*

T. A. Gabriel**Member**

- Task Force on Radiation Levels in the Experimental Halls at the SSC (DOE).

Invited papers

- "MICAP: A Program for Low Energy Neutron, Ion, and Gamma-Ray Transport and One of Its Applications in Calorimeter Design: Hydrogen Knock-In As a Method for Achieving Compensation," (with J. O. Johnson and J. Brau) Workshop on Detector Simulation for the SSC, Argonne National Laboratory, August 24–28, 1987.
- "Modifications of the High-Energy Transport Code (HETC) and Comparisons with Experimental Results," (with R. G. Alsmiller, Jr., F. S. Alsmiller, and O. W. Hermann) ANS Topical Conference on Theory and Practice in Radiation Protection and Shielding, Knoxville, TN, April 22–24, 1987.
- "Codes, Models, and Cross Sections for Use in Analyzing Compensated Calorimeters," Workshop on Compensated Calorimetry, Cal Tech, Pasadena, CA, September 10–11, 1985.

Referee

- *Nuclear Science and Engineering*
- *Nuclear Instruments and Methods*
- *Nuclear Technology/Fusion*

W. P. Gambill**Invited paper**

- "Thermal-Hydraulic Constraints on Water-Cooled Research Reactor Performance," Meeting at NBS, December 1985; *Nucl. Instru. Methods in Phys. Res.*, A249, 53, August 15, 1986.

Award

- Martin Marietta Energy Systems' Silver Acorn Award.

G. A. Geist**Member**

- Organizing Committee for First Conference on Hypercube Multiprocessors.

Invited talks

- "Matrix Factorization on a Hypercube Multiprocessor," (with M. T. Heath) Conference on Hypercube Multiprocessors, Knoxville, TN, August 26–27, 1985.

Invited lectures

- "Parallel LU Factorization with Pivoting on a Hypercube Multiprocessor," North Carolina State University, Raleigh, NC, April 1, 1986.
- "Efficient Communication Routines for Local-Memory Multiprocessors," North Carolina State University, Raleigh, NC, April 3, 1986.

Award

- Martin Marietta Energy Systems Publication Award, 1987.

J. A. George**Member**

Editorial Board of *Aequationes Mathematicae*.

- Editorial Board of *SIAM, J. Scientific and Statistical Computing*.
- Editorial Board of *Linear Algebra and Its Applications*.
- SIAM Council, January 1987 – January 1990.
- Computer Science Advisory Committee, Rensselaer Polytechnic Institute, Troy, NY, 1982–Present.
- Research Advisory Committee for the Clemson University Research Initiative Program in Discrete Mathematics and Computational Analysis, 1987.
- Organizing Committee, Gatlinburg X, Symposium on Numerical Algebra, Fairfield Glade, TN, October 1987.

Chairman

- Computer Science Graduate Committee, September 1, 1987.

Consultant

- Ontario Council on Graduate Studies for the M. Sc. Program in Computer Science at McMaster University, October 1986.

Organizer

- Minisymposium on Sparse Matrix Computation and Parallel Computing, SIAM National Meeting, Denver, CO, October 12–15, 1987.

Referee

- *SIAM, J. Scientific and Statistical Computing*
- *Linear Algebra and Its Applications*
- *Association for Computing Machinery*
- National Science Foundation, Office of Naval Research, Air Force Office of Scientific Research, and ARO Granting Agencies.

Invited lectures

- Seventh International Conference on Computing Methods in Applied Science and Engineering, Versailles, France, December 9–13, 1985.
- International Conference on Vector and Parallel Computing — Issues in Applied Research and Development, Loen, Norway, June 2–6, 1986. (Sponsored by Chr. Michelsen Institute and SIAM/SIAG on Supercomputing.)
- International Conference on Modern Problems in Numerical Analysis, USSR Academy of Sciences, Moscow, September 15–17, 1986.
- Workshop on Scientific Computing Using Parallel Architectures, Institute for Advanced Computer Studies, University of Maryland, April 6–8, 1987.
- SERC Numerical Analysis Summer School, University of Lancaster, England, July 12–31, 1987 (10 lectures).

A. B. Gustin

Award

- 1987 ANS RP&S Division Technical Service Award.

C. M. Haaland

Advisor

National Council on Radiation Protection and Measurements, Scientific Committee 63: Radiation Exposure Control in a Nuclear Emergency.

Invited lecture

- "Radiation: Fact and Fancy," Annual Meeting of the American Civil Defense Association, Dallas, TX, October 1986.

Referee

- *Journal of Civil Defense*
- *Journal of Health Physics*

J. A. Harvey**Member**

- ORNL Accelerators and Radiation Sources Review Committee.

Chairman

- Executive Committee, Electromagnetic Isotope Enrichment Facility Users Group, 1987.

Labor Coordinator

- Engineering Physics and Mathematics Division.

Referee

- *Physical Review C* and *Physical Review Letters*
- *Nuclear Science and Engineering*

N. A. Hatmaker**Member**

- Seminar Workshop on SCALE, Oak Ridge, TN, April 1986.
- 14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 1986.
- Engineering Physics and Mathematics Division Communications Survey Advisory Group, 1987.

Chairman

- Engineering Physics and Mathematics Division Ambience PIP Committee, 1987.

Representative

- EPIC representative in the Department of Energy's RECON User's Group annual meetings, 1980–1986.

Invited papers

- "The Radiation Shielding Information Center (RSIC): An Overview," (with B. F. Maskewitz and R. W. Roussin) IEA/ORAU Workshop on Passive Nuclear Reactors in the Far East, August 1985.
- "Nuclear Regulatory Commission Programs Are Supported by the Technology Resources of the Engineering Physics Information Centers," (with R. W. Roussin and J. E. White) Poster session, 14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 1986.

Award

- 1987 ANS RP&S Division Technical Service Award

M. T. Heath**Chairman**

- Organizing Committee, Third Conference on Hypercube Concurrent Computers.

Member

- Board of Directors, ACM-SIGNUM

Referee

- *Linear Algebra and Its Applications*
- *SIAM Journal Scientific and Statistical Computing*
- *IMA J. Numer. Anal.*
- *Mathematical Programming*
- *Parallel Computing*

Proposal reviewer

- AFOSR
- NSF

Award

- Martin Marietta Energy Systems' Publication Award.

D. T. Ingersoll**Member**

- Executive Committee, Radiation Protection and Shielding Division, American Nuclear Society.

Chairman

- Shielding Data Testing Subcommittee, Cross-Section Evaluation Working Group (CSEWG).
- Publications Committee, ANS Topical Conference on Radiation Protection and Shielding.
- Conference Coordinator, ANS Topical Conference on Radiation Protection and Shielding.
- U.S.-JASPER Shielding Program Working Group.

Secretary

Radiation Protection and Shielding Division, American Nuclear Society.

Invited seminar

- "Radiation Shielding Research at ORNL," Georgia Institute of Technology, October 31, 1985.

Referee

- *Nuclear Technology*

J. O. Johnson**Thesis**

- "Development and Evaluation of a Monte Carlo Code System for Analysis of Ionization Chamber Responses," Doctor of Philosophy Dissertation, University of Tennessee, Knoxville, TN, June 1987.

B. L. Kirk**Member**

- American Nuclear Society Computational Benchmark Problems Committee.
- Society for Industrial and Applied Math Special Interest Activity Group on Supercomputing.

Award

- 1987 ANS RP&S Division Technical Service Award

H. E. Klee**Member**

- Centralized Reliability Data Organization Data Evaluation Working Group.
- Centralized Reliability Data Organization Input/Output Working Group.
- Technical Program Committee, ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems.
- ORNL Reactor Review and Audit Committee.

Chairman

- Centralized Reliability Data Organization (CREDO) Steering Committee.
- Publication Committee, ANS/ENS International Topical Meeting on Advances in Human Factors in Nuclear Power Systems.

Section Editor

- Accident Analysis Section of the *Nuclear Safety Journal*.

Referee

- *Nuclear Science and Engineering*

Invited Book Chapter

- "CREDO — An Advanced Nuclear Reactor Reliability, Availability, and Maintainability Data Bank and Data Analysis Center," in *Reliability Data Banks*, Elsevier Applied Science Publishers, Ltd., United Kingdom (to be published).

D. C. Larson**Member**

- ORNL Salaried Employee Complaint Counselor.
- Evaluation Methods Subcommittee, CSEWG.
- Department of Energy Nuclear Data Committee.
- Office of Basic Energy Sciences (OBES) Committee on Nuclear Data for Fusion Reactor Applications.

Co-Chairman

- Engineering Physics and Mathematics Division seminars.
- General Purpose Evaluations Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Proposal reviewer

- Office of Basic Energy Sciences, Department of Energy, Low Energy Nuclear Physics.

Referee

- *Nuclear Science and Engineering*

W. E. Lever**Member**

- American Statistical Association Biometrics Society.

R. A. Lillie**Chairman**

- ORNL Reactor Experiments Review Committee.

Referee

- *Nuclear Technology*
- *Nuclear Technology/Fusion*
- *Journal of Fusion Energy*
- *Nuclear Science and Engineering*
- *Nuclear Instruments and Methods*

R. L. Macklin**Member**

- Engineering Physics and Mathematics Division Communication Survey Response Advisory Group.
- Engineering Physics and Mathematics Division Safety Inspection Quarterly Review.

Fellow

- American Association for the Advancement of Science.
- American Physical Society.

Referee

- *Nuclear Science and Engineering*
- *Physical Review*
- *Nuclear Physics*

R. E. Maerker**Member**

- ASTM E10.05 Subcommittee, 1978–present.
- Shielding Subcommittee, Cross Section Evaluation Working Group (CSEWG).
- Data Testing Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Invited paper

- "Application of the LEPRICON Methodology to Pressure Vessel Surveillance Dosimetry," Sixth ASTM-EURATOM Symposium on Reactor Dosimetry, Jackson Hole, WY, May 31 – June 5, 1987.

Awards

- Martin Marietta Energy Systems Publication Award, 1985.
- American Nuclear Society Best Paper Award, Radiation Protection and Shielding Division, 1985.

Referee

- *Nuclear Science and Engineering*
- *Journal of Nuclear Materials*, Amsterdam, Holland

R. C. Mann**Invited papers**

- "Methods for Computer Analysis and Comparison of Two-Dimensional Protein Patterns Obtained by Electrophoresis," NATO Advanced Study Institute on Pattern Recognition Theory and Applications, Spa, Belgium, June 1986.
- "Multi-sensor Integration Using Concurrent Computing," SPIE Conference on Infrared Sensors and Sensor Fusion, Orlando, FL, May 1987.

Invited lectures

- "Data Processing and Analysis in Flow Cytometry," Course taught at the E. I. DuPont de Nemours, Wilmington, Delaware, November 5, 1985.
- "Problems in Multi-parameter Data Analysis Specific to Flow Cytometry," 5th Flow Cytometry Workshop, Wilmington, DE, December 13, 1985.
- "Hypercube Concurrent Computer," 2nd Robot Vision Workshop, Aalborg University, Denmark, December 1986.
- "Motion Detection in the Presence of Changes in Illumination," 2nd Robot Vision Workshop, Aalborg University, Denmark, December 1986.
- "Quantitative Analysis of Digital Images Generated by Two-Dimensional Electrophoresis," 2nd Robot Vision Workshop, Aalborg University, Denmark, December 1986.

Reviewer

- DOE SBIR Program, 1984–Present.

C. March-Leuba**Thesis**

- "Interpretation of Subcriticality Measurements with Strong Spatial Effects," Master of Science Thesis, Nuclear Engineering, University of Tennessee, Knoxville, TN.

B. F. Maskewitz**Member**

- ANS-10 Subcommittee of the ANS Standards Committee (1965–1986).
- Ethics Committee of the Engineering Affairs Council of the American Association of Engineering Societies (1984–1988).
- ANS/CNS Sixth Pacific Basin Nuclear Conference, Beijing, China (PRC), September 7–11, 1987.

Invited seminars

- "RSIC and International Technical Information Exchange," presented in several nuclear research institutes of the Ministry of Nuclear Industry of China (PRC), April 12 – May 6, 1986 and September 5–26, 1987.

Invited lecture

- On Radiation Protection Topics in Summer School on Computers in Medical Research, sponsored by the South African Medical Research Council, February 29 – March 1, 1988, Cape Town, South Africa.

Invited paper

- "Overview on the Use of Computers in Modeling, Shielding, Radiotherapy, and Imaging," Annual Congress of the South African Association of Physicists in Medicine and Biology, March 2–4, 1988, Cape Town, South Africa.

Invited presentation

- Banquet Keynote Address, ANS Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22–24, 1987.

Energy Systems Representative

- DOE National Energy Software Center (1984–1987).

Coordinator

- Engineering Physics and Mathematics Quality Assurance and PIP.

Award

- 1987 ANS RP&S Division Technical Service Award

B. L. McGill**Award**

- 1987 ANS RP&S Division Technical Service Award.

T. J. Mitchell**Invited papers**

- "Bayesian Approaches to the Design of Computational Experiments," NSF Workshop on Efficient Data Collection: Design of Computational Experiments, UCLA, Los Angeles, CA, January 10, 1986.
- "Algorithms for Bayesian Variable Selection in Regression," (with J. J. Beuchamp) Computer Science and Statistics 18th Symposium on the Interface, Fort Collins, CO, March 20, 1986.
- "A Bayesian Approach to the (Design and) Analysis of Computational Experiments," Workshop on Design for Computer Experiments, University of Illinois, Champaign, IL, April 27–29, 1987.
- "A Bayesian Approach to the Design and Analysis of Computational Experiments," Joint Statistical Meetings, San Francisco, CA, August 24–27, 1987.
- "A Bayesian Approach to the Design and Analysis of Computational Experiments," Workshop on Design for Computer Experiments, Santa Fe, NM, September 21–22, 1987.
- "A Bayesian Approach to the Design and Analysis of Computational Experiments," 33rd Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21–23, 1987.

D. L. Moses**Member**

- Tower Shielding Reactor Subcommittee, ORNL Reactor Operations Review Committee.

Chairman

- Arrangements Committee, Oak Ridge/Knoxville Local Section of the American Nuclear Society.
- Nominations Committee, Sigma Xi Scientific Research Society.

Invited papers

- "Approaches to Passive Safety in Advanced Thermal Reactors," Thermal Reactor Safety Meeting, San Diego, CA, February 2-6, 1986.
- "An Examination of the Bases for Proposed Innovations in Reactor Safety Technology," Fourteenth Water Reactor Safety Information Meeting, National Bureau of Standards, Bethesda, MD, October 27-31, 1986.

Award

- Professional Engineer Certification, March 1987.

M. D. Morris**Associate Editor**

- *Journal of Statistical Computation and Simulation*

E. Ng**Invited paper**

- "Parallel Algorithms for Matrix Computations," (with A. Geist and M. Heath) in *The Characteristics of Parallel Algorithms*, pp. 233-251, MIT Press (1987).

Invited talks

- "Experiments with Method of Lines Solvers on a Shared-Memory Parallel Computer," (with S. Thompson and P. G. Tuttle) Sixth IMACS International Conference on Computer Methods for Partial Differential Equations, Lehigh University, Bethlehem, PA, June 23-26, 1987; Proc. pp. 161-166 (1987).

G. Ostrouchov**Invited talk and paper**

- "Parallel Computing on a Hypercube: An Overview of the Architecture and Some Applications," 19th Symposium on the Interface of Computer Science and Statistics, Philadelphia, PA, March 8-11, 1987.

Referee

- *Journal of the American Statistical Association*
- *The American Statistician*
- *Analytical Chemistry*

R. W. Peelle**Member**

- Cross Section Evaluation Working Group (CSEWG) Executive Committee.
- Technology Evaluation Committee, ORNL.
- Program Committee, September 1988 ANS Reactor Physics Division Topical Meeting.
- Program Committee, 1989 NBS Conference in honor of the 50th Anniversary of the Discovery of Fission.

Chairman

- CSEWG Covariance Data Subcommittee.

Reviewer

- Small Business Incentive research grant programs of the Department of Energy Office of Energy Research and of the National Science Foundation.

Referee

- *The Physical Review*
- *Nuclear Science and Engineering*

F. G. Perey**Member**

- Nuclear Energy Agency Nuclear Data Committee (NEANDC).

Chairman

- NEANDC Task Force to resolve discrepancies in the Fe 1.15 keV resonance parameters.
- User group of Floating Point Systems, Inc. 64-bit computers.

Referee

- *Nuclear Science and Engineering*
- *Physical Review*
- *Nuclear Physics*

R. T. Primm, III**Member**

- Executive Committee, Local Section, American Nuclear Society Reactor Review and Audit Committee, ORNL

Chairman

- American Nuclear Society Summer 1987 Session on Critical Measurements in Organically Moderated Systems.

V. A. Protopopescu**Invited lecture**

- "The Nonlinear Boltzmann Equation with Partially Absorbing Boundary Conditions - Global Existence and Uniqueness Results," 10th International Conference on Transport Theory, LaJolla, CA, March 23-27, 1987.

Invited paper

- "Extending Green's Function Formalism to General Nonlinear Equations," (with D. G. Cacuci and R. B. Perez) 4th International Workshop on Nonlinear Evolution Equations and Dynamical Systems, Balaruc-les-Bains, France, June 11–26, 1987.

Invited talks

- "Nonlinear Propagators: A New Method for Solving General Nonlinear Equations," ORAU Traveling Lecture, Department of Mathematics, Trinity College, San Antonio, TX, November 4, 1986.
- "Recent Results and Open Problems in Time-Dependent Transport Theory," ORAU Traveling Lecture, Department of Mathematics, University of Texas at San Antonio, San Antonio, TX, November 5, 1986.
- "The Abstract Time-Dependent Transport Problem," Mathematics Department, Indiana University, Bloomington, IN, December 10, 1985.

Referee

- *Journal of Statistical Physics*
- *Nuclear Science and Engineering*
- *Transport Theory and Statistical Physics*
- *Physics Letters A*

Reviewer

- Mathematical Reviews
- Zentralblatt für Mathematik

D. B. Reister**Member**

- Review of Industrial Energy Demand Models by the Energy Modeling Forum at Stanford University.

W. A. Rhoades**Member**

- Ad Hoc ORNL Review Committee on Software Development Methodology (SDM).

A. F. Rice**Award**

- 1987 ANS RP&S Division Technical Service Award.

R. W. Roussin**Member**

- Panel on Reference Nuclear Data, representative for American Nuclear Society, Radiation Protection and Shielding Division.
- ANS 6.2.2: Shielding Benchmark Subcommittee.
- ANS 6.1.2: Shielding Cross Sections Committee.
- Shielding Data Testing and Applications Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Chairman

- Methods and Formats Committee, Cross Section Evaluation Working Group (CSEWG)
- Radiation Protection and Shielding Division, American Nuclear Society (1986–1987).
- Planning Committee, Radiation Protection and Shielding Division, American Nuclear Society.

Invited papers

- "Assuring Data Quality from an Information Analysis Center Perspective," American Society for Information Science Meeting, Chicago, IL, October 1, 1986.
- "Radiation Shielding and Protection," Chapter in *Encyclopedia of Physical Science and Technology*, Vol. 11, Academic Press (1987).

Award

- 1987 ANS RP&S Division Technical Service Award.

Referee

- *Nuclear Science and Engineering*
- *Nuclear Technology/Fusion*
- *Trans. of Symposia on Space Nuclear Power Systems*

R. T. Santoro**Member**

- Honors and Awards Committee, Radiation and Protection Division, American Nuclear Society.
- Defensive Shields Program Technical Advisory Group.
- ORNL PhD Recruiter.

Program chairman

- ANS Topical Meeting on Theory and Practices in Radiation Protection and Shielding, April 22–24, 1987.

Fellow

- American Nuclear Society

Award

- Citation, Martin Marietta Michoud Division, Manned Flight Awareness Program.

Referee

- *Nuclear Science and Engineering — Fusion Technology*
- *Nuclear Technology*

R. L. Schmoyer**Invited paper**

- "Dose-Response Analysis Under Unimodality of Response-to-Dose," Conference on Order Restricted Inference, Iowa City, IA, September 10–13, 1985.

D. L. Selby**Member**

- ORNL Seed Money Committee, 1986.

Chairman

- Oak Ridge/Knoxville Section of American Nuclear Society, 1985–86.
- First International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, April 1986.
- Arrangements Committee, International Topical Meeting on Theory and Practices in Radiation Protection and Shielding, April 1987.
- Registration Committee for Topical Meeting on Population Exposures from the Nuclear Fuel Cycle.

Invited paper

- *ORNL Review* article.

C. O. Slater**Member**

- Program Committee of the ANS Radiation Protection and Shielding Division.

M. S. Smith**Member**

- ANS Mathematics and Computation Division.

Theses

- "The Formulation of the Streaming Ray Method for Electron Transport Calculations in Two Dimensions," PhD Dissertation, August 1987.

R. R. Spencer**Referee**

- *Nuclear Science and Engineering*
- *The Physical Review*

M. Terranova**Member**

- Alternate member of ANSI X3V1 Task Group 9, User/System Interfaces.
- Human Factors Society, Computer Systems Group, Metropolitan Chapter and Tidewater Chapter.
- Association for Computing Machinery, Special Interest Group on Human Computer Interaction.
- American Psychological Association, Division 14 — Industrial/Organizational Psychologists and Division 21 — Experimental Psychologists.
- IEEE Society for Systems, Man, and Cybernetics.
- IEEE Society for the Social Implications of Technology.

Board of Directors

- Matrix, Inc. (Center for New Businesses) — Technical Assistance Committee.

Affirmative Action Representative

- Engineering Physics and Mathematics Division.

D. K. Trubey**ANS representative**

- ANSI Committee N17: Research Reactors, Reactor Physics, and Radiation Shielding.

Chairman

- ANS-6: Radiation Protection and Shielding Subcommittee, Standards Committee, American Nuclear Society.
- ANS-6.4.3: Standards Working Group, Gamma-Ray Attenuation Data.
- Telecommunications Subcommittee of Technical Journals Committee, American Nuclear Society.

Award

- 1987 ANS RP&S Division Technical Service Award.

Computer Security Officer

- Engineering Physics and Mathematics Division.

SI Standards Coordinator

- Engineering Physics and Mathematics Division.

Referee

- *Nuclear Science and Engineering*

V. R. R. Uppuluri**Board Member**

- PRISM (Partnership for Resources and Initialities in Science and Mathematics), sponsored by ORNL and ORAU.

Associate Editor

- *Journal of Risk Analysis*, Plenum Press, Inc.

President

- Tennessee Mathematics and Computer Sciences Foundation, Inc.

Editor

- "Expert Judgment and Expert Systems," (with J. Mumpower, L. D. Phillips, and O. Renn) NATO ASI Series, Springer-Verlag (1987).
- "Uncertainty in Risk Assessment, Risk Management and Decision Making," (with V. T. Covello, L. B. Lave, and A. Moghissi) Plenum Press, NY (1987).

Invited papers

- "Prioritization Techniques Based on Stochastic Paired Comparisons," 1987 Joint Statistical Meetings, San Francisco, CA, August 1987.

- "Measures of Diversity Based on Fuzzy Multinomial Distribution," 46th Session of the International Statistical Institute, Tokyo, Japan, September 8–16, 1987.

Invited lecture

- "Prioritization Techniques Based on Paired Comparisons," NATO Advanced Study Institute, Istanbul, Turkey, June 28 – July 7, 1987.

R. C. Ward

Member

- SIAM Council.
- SIAM Program Committee.
- Organization Committee for Gatlinburg X Meeting.
- Advisory Committee, 1989 Sparse Matrix Symposium.

Chairman

- SIAM Activity Group on Linear Algebra.

Invited paper

- "Are Advances in Supercomputing Occurring Rapidly Enough?" Second International Conference on Supercomputing, Santa Clara, CA, May 4–5, 1987.
- "Mathematical Sciences Research at the Oak Ridge National Laboratory," presented to the Department of Mathematics, Northern Illinois University, Dekalb, IL, April 24, 1987.

Fellow

- American Association for Advancement of Science.

C. R. Weisbin

Member

- Martin Marietta Corporate Headquarters Steering Committee on Artificial Intelligence.
- Program Committee, IEEE International Conference on Robotics and Automation, 1987–1988.
- Advisory Committee, 1987 IEEE International Symposium on Intelligent Control, Philadelphia, PA, January 1987.
- DOE Representative to the Department of Defense, Joint Directors of Laboratories, Robotics Technology Panel reporting to Major General Cercy.

Chairman

- (Program) Second International Conference on Artificial Intelligence.

Director

- Center for Engineering Systems Advanced Research (CESAR).
- Robotics and Intelligent Control System Program (RISP).

Associate Editor

- *Journal of Impact*
- *IEEE Expert Intelligent Systems and Their Application*

Associate Professor

- Artificial Intelligence, Computer Science Department, University of Tennessee, Knoxville, TN.

Management Course

- Regional Advanced Management Program.

Special Assignments

- Topical Meeting on Nuclear Code Development, Tokyo, Japan, 1987.
- NATO Workshop on Mobile Robotics, Lisbon, Portugal, 1987.

Referee

- *Journal of Robotic Systems*
- *Journal of Impact*
- *IEEE Expert*

Proposal Referee

- National Science Foundation
- Department of Energy

Professional and Academic Honors

- IEEE Society Certificate of Appreciation.
- Who's Who in Technology Today: 5th Edition.

J. E. White**Member**

- ANS-10 Subcommittee of the ANS Standards Committee.

Invited paper

- "Nuclear Regulatory Commission Programs Are Supported by the Technology Resources of the Engineering Physics Information Centers," (with N. A. Hatmaker and R. W. Roussin) Poster session, 14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 1986.

Award

- 1987 ANS RP&S Division Technical Service Award.

B. A. Worley**Member**

- Executive Board, Mathematics and Computation Division, American Nuclear Society.

Invited talks/papers

- "Deterministic Sensitivity and Uncertainty Analysis for Level 3 Problems," Hydrocoin International Workshop on Groundwater Flow Modeling, Washington, DC, May 1987.
- "Deterministic Methods for Sensitivity and Uncertainty Analysis in Large-Scale Computer Models," (with E. M. Oblow, F. G. Pin, R. E. Maerker, J. E. Horwedel, R. Q. Wright, and J. L. Lucius) DOE/AECL 1987 Conference on Geostatistical, Sensitivity, and Uncertainty Methods for Groundwater Flow and Radionuclide Transport Modeling, San Francisco, CA, September 1987.

- "Deterministic Uncertainty Analysis," to be presented at the ANS Winter Meeting, Los Angeles, CA, November 1987.

Referee

- *Nuclear Science and Engineering*

T. Wright

Member

- American Statistical Association Advisory Committee to the U.S. Bureau of the Census.

Editorial Board

- *The American Journal of Mathematical and Management Sciences.*

Board of Directors and Treasurer

- Tennessee Mathematics and Computer Sciences Foundation.

Associate Professor

- (Mathematics) Knoxville College, Knoxville, TN.
- (Statistics) University of Tennessee, Knoxville, TN.

Referee

- *The American Journal of Mathematical and Management Sciences*
- *The American Statistician*
- *Metrika*

Reviewer

- *Mathematical Reviews*
- Academic Press
- National Science Foundation

ENGINEERING PHYSICS AND MATHEMATICS DIVISION SEMINARS AT ORNL

D. C. Larson, L. D. Trowbridge, and A. D. Solomon were seminar coordinators during the period covered by this report. Current seminar coordinators are M. S. Smith and C. H. Romine. The following seminars were held during July 1985 through September 1987.

E. C. Aifantis, Michigan Tech. University, Houghton, MI, "Thermodynamics, Phase Transitions and Non-Equilibrium Processes"

I. F. Akyildiz, Louisiana State University, Baton Rouge, LA, "Load Balancing in Distributed Computer Systems"

V. Alexiades, Engineering Physics and Mathematics Division, "The Critical Radius for Nucleation"

M. Ali, Computer Sciences, The University of Tennessee Space Institute, Tullahoma, TN, "Knowledge-Based Expert Systems for Real-Time Fault Monitoring and Diagnosis"

J. L. Barlow, Pennsylvania State University, University Park, PA, "Some Algorithms for the Solution of Equality Constrained Least Squares Problems"

J. Barry, The University of Tennessee, Knoxville, TN, "Two Parallel Computing Iterative Methods"

T. Bar-Noy, Nuclear Research Center, Negev, Beer-Sheva, Israel, "A Preliminary Study of an Expert System for Evaluating Scientific Publications"

R. Bass, Computing and Telecommunications Division, "Applications of Elastic and Viscoplastic Constitutive Models in Dynamic Analyses of Crack Run-Arrest Events"

C. K. Bayne, Computing and Telecommunications Division, "Detecting Isotopic Ratio Outliers"

Z. W. Bell, Computing and Telecommunications Division, "An Image Segmentation Algorithm for Nonfilm Radiography"

R. Billig, Encore Computer Corp., Marlboro, MA, "The Encore Multimax Computer System"

R. C. Block, Rensselaer Polytechnic Institute, Troy, NY, "Research at the RPI Electron Linear Accelerator"

J. R. Bourne, Department of Electrical Engineering and Biomedical Engineering, Vanderbilt University, Nashville, TN, "Experience in Building Intelligent Systems"

G. Brady, University of Lowell, Lowell, MA, "The Measurement and Importance of Neutron Scattering Cross Sections in Uranium"

S. Breuer, Tel Aviv university, Tel Aviv, Israel, "Decay Theorems for Nonlinear Dirichlet Problems in Semi-infinite Cylinders"

V. R. Brown, Lawrence Livermore National Laboratory, Livermore, CA, "Isospin Distributions of RPA Quadrupole Strength: Comparison to Pion, Nucleon, and Electromagnetic Experiments"

G. Caginalp, University of Pittsburgh, Pittsburgh, PA, "Phase Field Methods for Solidification"

B. Char, University of Waterloo, Ontario, Canada, "A Computer Algebra System"

- R. Cheng, University of Maryland, College, Park, MD, "Delta-Trigonometric and Spline-Trigonometric Methods for Solving Dirichlet Problems Using the Single Layer Potential Representation"
- E. Chu, University of Waterloo, Ontario, Canada, "Parallel Orthogonal Decomposition of Large Sparse Matrices"
- G. P. Chubb, SofTech, Inc., Fairborn, OH, "Simulation and Software Engineering in Design and Testing of Large-Scale, Software-Intensive Systems"
- R. A. Cliff, Advanced Research Projects Agency, Washington, DC, "Architectural Issues in Intelligent Autonomous Systems"
- C. Cox, Clemson University, Clemson, SC, "Some Aspects of Vector/Parallel Processing Least Squares Finite Element Codes"
- D. E. Cullen, IAEA Nuclear Data Section, Vienna, Austria, "Cross-Section Processing Verification Project of the International Atomic Energy Agency (IAEA)"
- J. H. Curry, University of Colorado, Boulder, CO, "On Zero-Finding Algorithms"
- G. Cybenko, Tufts University, Medford, MA, "Linear Algebra in Signal Processing"; and "Multiprocessor Scheduling by Simulated Annealing"
- C. Douglas, IBM Thomas J. Watson Research Center, Yorktown Heights, NY, "Estimates for Multigrid Rates of Convergence with General Smoothing and Acceleration"
- T. H. Dunigan, Engineering Physics and Mathematics Division, "Hypercube Parallel Processors"; and "Tutorial: New Text Processing Commands"
- R. Eckmiller, Institute of Biocybernetics, University of Düsseldorf, Federal Republic of Germany, "Motor Program Generation in Primates and Robots"
- R. R. Gawronski, University of West Florida, Pensacola, FL, "Adaptive Optimization of a Robot Control System with the Application of the Orthogonal Expansion of Control Signals"
- G. A. Geist, Engineering Physics and Mathematics Division, "Solving Finite-Element Problems with Parallel Multifrontal Schemes"
- G. A. Geist, E. Ng, C. H. Romine, and M. T. Heath, Engineering Physics and Mathematics Division, "Hypercube Conference Preview"
- D. Geman, University of Massachusetts, Amherst, MA, "Locating Object and Texture Boundaries in Digital Images"
- D. G. Gosslee, Engineering Physics and Mathematics Division, "Models for Drug Mixture Tests"
- L. J. Gray, Engineering Physics and Mathematics Division, "Electroplating Simulation Using Boundary Elements"; and "Fractal Models for the AC Response of a Rough Interface"
- E. Greenbaum, Chemical Technology Division, "Applied Photosynthesis: Composite Electronic Materials and Fuel Synthesis"
- S. Grossberg, Center for Adaptive Systems, Boston University, Boston, MA, "A Massively Parallel Architecture for a Self-Organizing Neural Pattern Recognition Machine: Attentive Regulation of Learning and Information Processing"

- M. T. Heath, Engineering Physics and Mathematics Division, "Parallel Cholesky Factorization on a Multiprocessor"
- J. Holdeman, Computing and Telecommunications Division, "New Velocity and Pressure Elements for Two-Dimensional Divergence-Free Fluid Flow"
- J. Jackson, University of Wisconsin, Madison, WI, "Logical Based Knowledge Representation Languages Can Represent Complex Objects in a Natural Manner"
- D. Jefferson, UCLA, Los Angeles, CA, "Distributed Simulation and Time Warp on the Caltech Hypercube Computer"
- E. Jessup, Yale University, New Haven, CT, "A Divide and Conquer Approach to Eigenvalue and Singular Value Problems"
- W. F. Lawkins, Engineering Physics and Mathematics Division, "Some Problems in Incompressible Rotating Fluid Dynamics and the Stability of Rotating Fluid/Mechanical Systems"
- R. Leveque, University of Washington, Seattle, WA, "Cartesian Grid Methods for Compressible Flow in Irregular Regions"
- E. Lloyd, University of Pittsburgh, Pittsburgh, PA, "Heuristics for PLA Foldings"
- R. A. Manning, Control Data Corp., Knoxville, TN, "Comparison of Direct Methods for Solving Block Tridiagonal Linear Systems on the Control Data CYBER 205"
- H. L. Martin, Instrumentations and Controls Division, "Telerobotics: Human Supervised Manipulation for Hostile Environments"
- R. Mills, Ohio State University, Columbus, OH, "Supersymmetry Methods for Disordered Systems"
- T. J. Mitchell, Engineering Physics and Mathematics Division, "Some Ideas for Research in the Design and Analysis of Computational Experiments"
- T. J. Mitchell and M. D. Morris, Engineering Physics and Mathematics Division, "A Bayesian Approach to the Design and Analysis of Computational Experiments"
- M. D. Morris, Engineering Physics and Mathematics Division, "Bayes Estimation of a Nonstochastic Response Surface with Application to Approximation of a Computer Model"
- D. Mutchler, Naval Research Laboratory, Washington, DC, "A Stochastic Analysis of the Availabilities of Four Distributed Algorithms for Maintaining the Consistency of a Replicated File in the Face of Network Partitioning"
- J. L. Nazareth, University of California, Berkeley, CA, "New Directions in Linear Programming"
- H. Neunzert, University of Kaiserslautern, Federal Republic of Germany, "Simulation Procedures for the Nonlinear Vlasov-Boltzmann Equation"
- S. L. Newsome, Rensselaer Polytechnical Institute, Troy, NY, "Natural Problem Solving Strategies and Computer Program Comprehension: Cognitive Mismatching"
- E. Ng, Engineering Physics and Mathematics Division, "Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems"
- Y. Oka, University of Tokyo, Tokyo, Japan, "Shielding Experiments and Method Development of Uncertainty and 3-D Transport Analysis"

- G. Ostrouchov, Engineering Physics and Mathematics Division, "Statistical Computing on a Hypercube"; and "Underwater Passive Target Tracking and Position Prediction"
- C. Prakash, CHAM of North America, "PHOENICS, A Computer Package for Fluid Flow and Diffusion Problems"
- A. B. Pritsker, Pritsker and Associates, Inc., Fairborn, OH, "Simulation Modeling: Augmenting Your Knowledge Base"
- C. H. Romine, Engineering Physics and Mathematics Division, "Factorization Methods for the Parallel Solution of Linear Systems"
- Y. Ronen, Ben Gurion University, Israel, "Applications of the Generalized Bias Operator to Reactor Physics Problems"
- W. V. Saarloos, Bell Laboratories, Murray Hill, NJ, "Nonlinear Dynamic Effects of Front Propagation in Explosive Crystallization"
- T. L. Saaty, University of Pittsburgh, Pittsburgh, PA, "Decision-Making in Complex Environments"
- R. T. Santoro, Engineering Physics and Mathematics Division, "Defensive Shield Demonstration Program for the SDI"
- D. Sarafyan, Department of Mathematics, University of New Orleans, New Orleans, LA, "Runge-Kutta Methods from Their Origins to Most Recent Developments"; and "Continuous Approximate Solution of Ordinary Differential Equations by Sarafyan Methods"
- M. Saunders, Stanford University, Stanford, CA, "Linear Programming: An Application of Sparse Linear Least Squares"
- R. L. Schmoyer, Engineering Physics and Mathematics Division, "Dose-Response Analysis Under Unimodality of Response-to-Dose"
- J. C. Schryver, Engineering Physics and Mathematics Division, "Performance Measurement of Complex Man-Vehicle Systems"
- A. D. Solomon, Engineering Physics and Mathematics Division, "Some Aspects of Modeling Latent Heat Thermal Energy Storage in Space Applications"
- W. Stuetzle, Statistics Science Department, University of Washington, Seattle, WA, "Computing Environments and Graphics for Data Analysis"
- H. H. Szu, Naval Research Laboratory, Washington, DC, "Superconducting Optical Neurocomputers"
- M. A. Terranova, Engineering Physics and Mathematics Division, "Using Measures of Learning Rate and Scholastic Aptitude as Predictors of Performance"
- S. Thompson, Engineering Physics and Mathematics Division, "Implementation of Molecular Polymer Models on the Intel iPSC Hypercube"; "RKST35: An Adaptive Runge-Kutta ODE Solver for Rootfinding and Interpolation"; and "The Role of Mathematical Software Libraries"
- Y. Tikochinsky, Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, Israel, "Estimation of Inverse Temperature and Other Lagrange Multipliers — The Dual Distribution," joint seminar with Physics Division

- V. R. R. Uppuluri, Engineering Physics and Mathematics Division, "Measures of Uncertainty Used in Expert Systems"; and "Some Hybrid Probability Distributions"
- J. Usgersohn, VLSI Technology, Inc., San Jose, CA, "Learning in Neural Networks"
- Y. Varol, University of Southern Illinois, Carbondale, IL, "Error Recovery in Concurrent Processing Systems: Global Checkpoint Rollback Strategies"; and "Extendible Hashing with Double Directories"
- C. Vaughan, Department of Applied Mathematics, University of Virginia, Charlottesville, VA, "Implementation of Iterative Methods on Parallel Computers"
- V. R. Voller, University of Minnesota, Minneapolis, MN, "Analysis of Metallurgical Solidification Problems"; and "Numerical Methods for Analysis of Solidification Problems"
- C. R. Weisbin, Engineering Physics and Mathematics Division, "CESAR Research in Intelligent Machines: Past and Future"; and "Intelligent Machines: Progress and Opportunities"
- R. Wigmans, Dutch Institute of High-Energy Physics, Amsterdam, "Compensation Mechanism in Hadron Calorimetry"
- P. Williams, Lehigh University, Bethlehem, PA, "Iterative Solution of a Non-Linear System Arising in Phase Change Problems"; and "A Vectorized Implicit Difference Scheme for a Three-Dimensional Stefan Problem"
- A. Wong, Oak Ridge High School, Oak Ridge, TN, "Pattern Recognition Through Perceptrons"
- P. H. Worley, Engineering Physics and Mathematics Division, "Minimal Information Algorithms and Parallel Computation"
- T. Wright, Engineering Physics and Mathematics Division, "On Variable Size Simple Random Sampling from a Finite Population"
- D. M. Young, Center for Numerical Analysis, The University of Texas at Austin, Austin, TX, "Iterative Algorithms and Software for the Solution of Nonsymmetric Linear Systems"
- Z. Zlatev, Riso National Laboratory, Roskilde, Denmark, "Solving Large and Sparse Linear Least-Squares Problems by Conjugate Gradients Algorithms"
- D. Zwillinger, Institute for Defense Analysis, Princeton, NJ, "A New Approach to Phase Coarsening"

PUBLICATIONS

ADAMS, S. M.,* C. A. BURTIS,* AND J. J. BEAUCHAMP

"Integrated and Individual Biochemical Responses of Rainbow Trout (*Salmo Gairdneri*) to Varying Durations of Acidification Stress," *Comp. Biochem. Physiol.* **82C**(2), 301 (1985). (1.45)^f

ALEXIADES, V., AND E. C. AIFANTIS*

"On the Thermodynamic Theory of Fluid Interfaces: Infinite Intervals, Equilibrium Solutions, and Minimizers," *J. Colloidal and Interface Sci.* **111**, 119 (1986). (1985)

ALEXIADES, V., J. B. DRAKE, G. A. GEIST, G. E. GILES,* A. D. SOLOMON, AND R. F. WOOD*

"Mathematical Modeling of Laser Induced Ultrarapid Melting and Solidification," ORNL-6129 (March 1986). (1.2)

ALEXIADES, V., AND A. D. SOLOMON

"Critical Radius for Nucleation," ORNL/TM-9931 (April 1986). (1.3)

ALEXIADES, V., A. D. SOLOMON, AND D. G. WILSON

"The Formation of a Solid Nucleus in Supercooled Liquid," ORNL-6280 (June 1986). (1.5)

ALSMILLER, R. G., JR., F. S. ALSMILLER, AND T. A. LEWIS*

"Calculated Fraction of an Incident Current Pulse That Will Be Accelerated by an Electron Linear Accelerator and Comparisons with Experimental Data," ORNL/TM-10010 (May 1986); *Nucl. Instrum. Methods in Phys. Research A***256**, 409 (1987). (3.16)

ALSMILLER, R. G., JR., J. M. BARNES,* AND J. D. DRISCHLER

"Neutron-Photon Multigroup Cross Sections for Neutron Energies ≤ 400 MeV (Revision 1)," ORNL/TM-9801 (February 1986); *Nucl. Instrum. Methods in Phys. Research A***249**, 455 (1986). (3.17)

BARHEN, J.

"Hypercube Ensembles: An Architecture for Intelligent Robots," Chapter 8 in *Special Computer Architectures for Robots and Automation*, Professor J. Graham, Ed., pp. 195-236, Gordon and Breach, NY (1987). (4.9)

BARHEN, J., AND J. F. PALMER*

"The Hypercube in Robotics and Machine Intelligence," *Computers in Mech. Eng. J.* **4**(5), 30 (1986). (4.14)

BEALS, R.,* AND V. PROTOPOPESCU

"Abstract Time-Dependent Transport Equations," *J. Math. Anal. Appl.* **121**, 370 (1987). (1985)

*Not a member of Engineering Physics and Mathematics Division.

^fIn most cases, the number shown in parentheses following the publication corresponds to the number of an abstract included in this report. In some cases, the number is a year, which means the abstract was published in an earlier progress report published that year.

BEAUCHAMP, J. J., AND D. S. ROBSON*

"Transformation Considerations in Discriminant Analysis," *Commun. Statist.-Simula.* **15**(1), 147 (1986). (1.46)

BHUIYAN, S. I.,* R. W. ROUSSIN, J. L. LUCIUS,* J. H. MARABLE, AND D. E. BARTINE*

"Development of Simplified Methods and Data Bases for Radiation Shielding Calculations for Concrete," ORNL/TM-8629 (June 1986). (3.1)

BOEGLY, W. J., JR.* R. B. DREIER,* D. D. HUFF,* A. D. KELMERS,* D. C. KOCHER,* S. Y. LEE,* F. R. O'DONNELL,* F. G. PIN, AND E. D. SMITH*

"Characterization Plan for Solid Waste Storage Area 6," ORNL/TM-9877 (December 1985). (4.114)

BOWMAN, K. O.

"The Laboratory for Gastroenterology at Gumma University," *Scientific Bulletin* **10**(1), 111 (1985). (1.55)

"Small Sample Properties of Statistics — Computer Algorithmic Approach," Thesis for Doctorate in Engineering Degree, University of Tokyo, Tokyo, Japan (1986). (1.50)

"Total Quality Control at the Kansai Electric Power Company," *ONR Scientific Bulletin* **10**(3) (1985). (1.54)

BOWMAN, K. O., H. K. LAM,* AND L. R. SHENTON*

"Series for Student's Non-Central t Under Exponential Sampling with Comments Due to H. P. Mulholland," *Commun. Statist.-Simula.* **15**(3), 697 (1986). (1.56)

BOWMAN, K. O., AND L. R. SHENTON*

"The Dark Side of Asymptotics and Moment Series," *Sankhyā: The Indian Journal of Statistics* **48**, Series A, Pt. 2, 219 (1986). (1985)

"The Distribution of a Moment Estimator for a Parameter of the Generalized Poisson Distribution," *Commun. Statist.-Simula. Comput.* **14**(4), 867 (1985). (1985)

"The Two Color Urn Model: Recursions for the Moments," *Commun. Statist.-Simula.* **15**(3), 787 (1986). (1.64)

"A Reinforcement-Depletion Urn Model — Part I: A Contiguity Model," *Ann. Stat. Math. A* **38**(2), 233 (1986). (1985)

BROWNE, E. A.,* D. B. REISTER, AND L. D. TROWBRIDGE

"A Comparison Study of the RAMSGAS Model and the National Energy Policy Plan Projections to 2010," ORNL/TM-10159 (November 1986). (4.76)

BROWNE, E. A.,* D. B. REISTER, L. D. TROWBRIDGE, J. V. CONOPASK,* E. HICKS,* AND P. MIHLMESTER*

"The Research and Development Analysis Modeling System World Natural Gas Model (RAMSGAS) Final Documentation," ORNL/TM-10157 (December 1986). (4.77)

BURNS, T. J., R. D. CHEVERTON,* G. F. FLANAGAN, J. D. WHITE,* D. G. BALL,* L. B. LAMONICA,* AND R. OLSON*

"Preliminary Development of an Integrated Approach to the Evaluation of Pressurized Thermal Shock As Applied to the Oconee Unit 1 Nuclear Power Plant," ORNL/TM-9176 (NUREG/CR-3770) (May 1986). (3.61)

BYWATER, R. L., JR.*

"Gamma-Ray Production Cross Sections for 0.9 to 20 MeV Neutron Interactions with ^{10}B ," ORNL/TM-10191 (September 1986). (2.1)

CACUCI, D. G.

"Deterministic Sensitivity Theory for Nonlinear Systems: The Forward and the Adjoint Method," ORNL/TM-10058 (August 1986). (3.79)

CACUCI, D. G., R. B. PEREZ, AND V. PROTOPOPESCU

"Propagators for General Nonlinear Equations," ORNL/TM-10016 (May 1986). (3.83)

CAMPBELL, D. J.,* V. H. GUTHRIE,* J. R. KIRCHNER,* H. M. PAULA,* B. C. ELLISON,* F. M. DYCUS,* AND G. F. FLANAGAN

"Risk Assessment Application to NRC Inspection Progress Report for the Period January 1985 to January 1986," ORNL/TM-10001 (NUREG/CR-4560) (June 1986). (3.103)

CARLTON, R. F.,* J. A. HARVEY, R. L. MACKLIN, C. H. JOHNSON,* AND B. CASTEL*

"Nuclear Structure of ^{49}Ca Above 5 MeV Excitation from $n + ^{48}\text{Ca}$ and Astrophysics for 30-keV Neutrons," *Nucl. Phys. A* **465**, 274 (1987). (2.4)

CHU, E.,* AND A. GEORGE

"QR Factorization of a Dense Matrix on a Shared-Memory Multiprocessor," ORNL/TM-10581 (October 1987). (1.110)

CLINARD, J. A.,* AND G. A. GEIST

"Implementing Fracture Mechanics Analysis on a Distributed-Memory Parallel Processor," ORNL/TM-10367 (March 1987). (1.111)

CODDENS, G. P.,* N. SALAH,* J. A. HARVEY, N. W. HILL,* AND N. M. LARSON*

"Resonance Structure of $^{33}\text{S} + n$ from Transmission Measurements," *Nucl. Phys. A* **469**, 480 (1987). (2.3)

CRAMER, S. N., J. GONNORD,* AND J. S. HENDRICKS*

"Monte Carlo Techniques for Analyzing Deep-Penetration Problems," *Nucl. Sci. Eng.* **92**, 280 (1986). (1985)

CRAMER, S. N., AND J. S. TANG*

"Variance Reduction Methods Applied to Deep-Penetration Monte Carlo Problems," ORNL/TM-9643 (January 1986). (1985)

DAVIS, G. J.*

"Column LU Factorization with Pivoting on a Hypercube Multiprocessor," ORNL-6219 (November 1985). (1.112)

DERRIEN, H.,* G. de SAUSSURE, R. B. PEREZ, N. M. LARSON,* AND ROGER L. MACKLIN*

"R-Matrix Analysis of the ^{239}Pu Cross Sections Up to 1 keV," ORNL/TM-10098 (June 1986). (2.34)

DERRIEN, H.,* N. M. LARSON,* G. de SAUSSURE, AND R. B. PEREZ

"R-Matrix Analysis of the ^{241}Pu Cross Sections Up to 100 eV," *Nucl. Sci. Eng.* **96**, 58 (1987). (2.36)

DICKENS, J. K.

"Current Status of Decay Heat Measurements, Evaluations, and Needs," ORNL/TM-10094 (July 1986). (2.37)

"Fission Product Yields for Fast Neutron Fission of $^{243,244,246,248}\text{Cm}$," *Nucl. Sci. Eng.* **96**, 8 (1987). (2.22)

"Half Life of ^{57}Ni ," *J. Radioanal. Nucl. Chem. Letters* **103**, 273 (1986). (2.24)

"Study of Radionuclides Created by $^{60}\text{Ni}(\gamma, xn\text{ } \gamma p)$ Reactions for Bremsstrahlung Photons Produced by 140-MeV Electrons," ORNL/TM-9764 (March 1986). (2.23)

DICKENS, J. K., AND D. C. LARSON

"Gamma-Ray Decay of Levels in ^{53}Cr ," ORNL-6418 (October 1987). (2.5)

DICKENS, J. K., AND J. W. McCONNELL*

"Yields of Fission Products Produced by Thermal-Neutron Fission of ^{243}Cm ," *Phys. Rev. C* **34**(2), 722 (1986). (2.21)

DICKENS, J. K., J. W. McCONNELL,* K. M. CHASE,* H. W. HENDEL,* E. B. NIESCHMIDT,* AND F. Y. TSANG*

"Measurements of the Neutron and Gamma-Ray Fluences in the TFTR Test Cell Due to a Point Source Simulating D-T Fusion Plasma Neutron Production," *Fusion Tech.* **12**, 270 (1987). (2.26)

DICKENS, J. K., AND S. RAMAN*

"Fission-Product Yield Data from the US/UK Joint Experiment in the Dounreay Prototype Fast Reactor," ORNL-6266 (April 1986). (2.20)

DIFILIPPO, F. C., AND R. B. PEREZ

"On the Excitation of Neutron Flux Waves in Reactor Core Transients," *Nucl. Sci. Eng.* **94**, 66 (1986). (3.84)

DRAKE, J. B.

"A Study of the Optimal Transition Temperature of PCM Wallboard for Solar Energy Storage," ORNL/TM-10210 (September 1987). (1.8)

DRAKE, J. B., G. A. GEIST, J. M. MARTIN,* C. SERBIN,* A. D. SOLOMON, J. J. TOMLINSON,* P. GRODZKA,* P. McCORMICK,* J. PRICE,* AND S. BROWN*

"PCMSOL — Simulation Code for a Passive Solar Structure Incorporating Phase Change Materials," ORNL-6359 (January 1987). (1.9)

DRAKE, J. B., G. A. GEIST, M. D. MORRIS, A. D. SOLOMON, J. M. MARTIN,* AND J. J. TOMLINSON*

"Design of PCM Enhanced Passive Solar Structures," ORNL-6281 (March 1987). (1.10)

DRAKE, J. B., W. F. LAWKINS, B. A. CARRERAS,* H. R. HICKS,* AND V. E. LYNCH*

"Implementation of a 3-D Nonlinear MHD Calculation on the Intel Hypercube," ORNL-6335 (August 1987). (1.115)

DUNIGAN, T. H.

"A Message-Passing Multiprocessor Simulator," ORNL/TM-9966 (May 1986). (1.116)

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American Nuclear Society National Topical Conference on Reactor Physics and Safety, Saratoga Springs, NY, September 17–19, 1986; Proc. NUREG/CP-0080, Vol. 2 (1986)

DICKENS, J. K., "Current Status of Decay Heat Measurements, Evaluations, and Needs," p. 671. (2.37)

DIFILIPPO, F. C., "Designing CNR, A Very High Thermal Neutron Flux Facility," p. 810. (3.59)

DIFILIPPO, F. C., R. M. MOON,* W. R. GAMBILL, R. T. PRIMM III, AND C. D. WEST,* "An Intense Steady State Neutron Source — the CNR Reactor," p. 792. (3.60)

Fifth Coordination Meeting of Participants in the Office of Basic Energy Sciences Program to Meet High-Priority Nuclear Data Needs of the Office of Fusion Energy, Argonne, IL, September 17-19, 1986; Proc. DOE/ER/02490-4, 1986

FU, C. Y., "Validation of the TNG Code with Double Differential (n,xn) Data at 14 and 26 MeV," p. E-5. (2.27)

HETRICK, D. M., "Calculation and Evaluation of $^{58,60}\text{Ni}$ for ENDF/B-VI." (2.31)

LARSON, D. C., "Measurement Activities," (Task Force A Report). (2.44)

Eighth Annual DOE Low-Level Waste Management Forum, Denver, CO, September 22-26, 1986; Proc. Technical Session V, Performance Assessment (February 1987)

PIN, F. G., J. E. HORWEDEL,* E. M. OBLOW, AND J. L. LUCIUS,* "ADGEN: A System for Automated Sensitivity Analysis of Predictive Models," p. 86. (4.102)

Second Conference on Hypercube Multiprocessors, Society for Industrial and Applied Mathematics, Knoxville, TN, September 29-30, 1986; Proc. SIAM Philadelphia (1987)

BOWMAN, K. O., AND M. T. ROBINSON,* "Studies of Random Number Generators for Parallel Processing," p. 445. (1.57)

DAVIS, G. J.,* R. E. FUNDERLIC,* AND G. A. GEIST, "A Hypercube Implementation of the Implicit Double Shift Qk Algorithm," p. 619. (1.113)

DUNIGAN, T. H., "Hypercube Performance," p. 178. (1.119)

EINSTEIN, J. R., J. BARHEN, D. JEFFERSON,* "Virtual-Time Operating-System Functions for Robotics Applications on a Hypercube," p. 100. (4.31)

GEIST, G. A., "Solving Finite Element Problems with Parallel Multifrontal Schemes," p. 656. (1.122)

GEORGE, A., J. LIU,* AND E. NG, "Communication Reduction in Parallel Sparse Cholesky Factorization on a Hypercube," p. 576. (1.134)

HEATH, M. T., "Hypercube Applications at ORNL," p. 395. (1.137)

JONES, J. P., "Application of the NCUBE Hypercube Concurrent Processor to Image Processing and Artificial Vision," (full paper not submitted for proceedings). (4.48)

JORGENSEN, C. C., "Neural Network Recognition of Robot Sensor Graphs Using Hypercube Computers," (full paper not submitted for proceedings). (4.34)

MANN, R. C., "Analysis of Two-Dimensional Protein Patterns Using the NCUBE Hypercube," (full paper not submitted for proceedings). (4.53)

ROMINE, C. H., "Parallel Solution of Triangular Systems on a Hypercube," p. 552. (1.150)

VAUGHAN, C., "Performance Modeling of Three Iterative Methods on a Hypercube," p. 692. (1.152)

WARD, R.,* G. A. GEIST, AND W. H. BUTLER,* "Density Functional Theory and Parallel Processing," p. 473. (1.155)

1986 Fall Divisional Meeting of the American Physical Society, Vancouver, B. C., Canada, October 9-11, 1986

MACKLIN, R. L., J. A. HARVEY, N. W. HILL,* AND G. L. TWEED,* "Neutron Capture and Total Cross Sections of $^{144}\text{Sm} + n$." (2.8)

Research in Multiprocessing Special Interest Group (RIMSIG) Symposium, Santa Fe, NM, October 22-23, 1986

BARHEN, J., "Simulation of the Stochastic Dynamics of Neural Networks on a Hypercube Supercomputer." (4.5)

EINSTEIN, J. R., "Robot Control with a Hypercube: Virtual-Time Functions for the Node's Operating System." (4.28)

JONES, J. P., "Image Processing on a Hypercube Concurrent Multiprocessor." (4.47)

MANN, R. C., "Quantitative Analysis of Two-Dimensional Protein Patterns Using an NCUBE Hypercube." (4.54)

NG, E., "Solution of Sparse Positive Definite Systems on a Shared-Memory Multiprocessor." (1.146)

ROMINE, C. H., "Columns vs. Rows for Gaussian Elimination with Pivoting on a Hypercube Multiprocessor." (1.149)

Workshop on Automation and Robotics for Military Applications, Huntsville, AL, October 22-23, 1986

BARHEN, J., "Intelligent Operating Systems for Battlefield Robotics: Real-Time Performance on a VLSI Hypercube Supercomputer." (4.7)

KAMMER, D. W.,* G. de SAUSSURE, AND C. R. WEISBIN, "A Real-Time Expert System for Control of an Autonomous Mobile Robot and for Diagnosing Unexpected Occurrences." (4.25)

SPIE Cambridge Symposium on Optical and Optoelectronic Engineering, Cambridge, MA, October 26-31, 1986; Proc. SPIE Vol. 729, Space Station Automation II (1986)

EINSTEIN, J. R., J. BARHEN, AND D. JEFFERSON,* "A Virtual-Time Operating Systems Shell for a Hypercube in Robotics Applications," p. 424. (4.30)

WEISBIN, C. R., G. deSAUSSURE, AND D. W. KAMMER,* "A Real-Time Expert System for Control of an Autonomous Mobile Robot Including Diagnosis of Unexpected Occurrences," p. 49. (4.44)

14th Water Reactor Safety Information Meeting, National Bureau of Standards, Gaithersburg, MD, October 27-31, 1986; Proc. NUREG/CP-0082 (1987)

HATMAKER, N. A., R. W. ROUSSIN, AND J. E. WHITE, "Nuclear Regulatory Commission Programs Supported by the Technology Resources of the Engineering Physics Information Centers," (poster session only not in proceedings). (5.8)

MOSES, D. L., "An Examination of the Bases for Proposed Innovations in Reactor Safety Technology," Proc. Vol. 1, p. 401. (3.64)

The Impact of Supercomputing on Air Force R&D Meeting, Elgin Air Force Base, FL, November 3-5, 1986

GEORGE, J. A., "Sparse Cholesky Factorization on a Local-Memory Multiprocessor." (1.129)

Talk, Department of Computer Sciences, University of Tennessee, Knoxville, TN, November 5, 1986

NG, E., "Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems." (1.145)

Talk, University of Tennessee, Knoxville, TN, November 6, 1986

MITCHELL, T. J., "Bayesian Approaches to the Design of Computational Experiments." (1.83)

1986 Winter Meeting of the American Nuclear Society, Washington, DC, November 16-21, 1986; Trans. Am. Nucl. Soc. 53 (1986)

CACUCI, D. G., R. B. PEREZ, AND J. MARCH-LEUBA,* "Limit Cycles and Bifurcations in Nuclear Systems," p. 239. (3.80)

FU, C. Y., AND D. M. HETRICK,* "Evaluation and Testing of Double Differential $F(\pi, \pi')$ Cross Sections," p. 409. (3.2)

JOHNSON, J. O., AND T. A. GABRIEL, "Development and Testing of a Monte Carlo Code System for Analysis of Ionization Chamber Responses," p. 408. (3.35)

TRUBEY, D. K., AND Y. HARIMA,* "New Buildup Factor Data for Point Kernel Calculations," p. 416. (5.2)

IAEA Specialists' Meeting on Covariance Methods and Practices in the Field of Nuclear Data, Rome, Italy, November 17-19, 1986

PEELLE, R. W., "Evaluating Nuclear Data Uncertainty: Progress, Pitfalls, and Prospects." (2.39)

Eighth Annual IAEE North American Conference on the Changing World Energy Economy, Massachusetts Institute of Technology, Cambridge, MA, November 19-21, 1986; Proc. (May 1987)

REISTER, D. B., "Energy Substitution Patterns in EMF-8," abstract only, p. 295. (4.83)

REISTER, D. B., "Future Demand for Fuel and Electricity," p. 417. (4.82)

REISTER, D. B., "Specification of Fuel Share Models," p. 461. (4.84)

TROWBRIDGE, L. D., D. B. REISTER, J. V. CONOPASK,* AND E. HICKS,* "Penetration of Unconventional Oil into World Markets," p. 130. (4.95)

Talk, Statistics Department, University of Tennessee, Knoxville, TN, November 20, 1986

WRIGHT, T., "Does the Uninformed Person Always Use a Uniform Prior Distribution?" (1.107)

Intelligent Autonomous Systems Conference, Amsterdam, The Netherlands, December 8-11, 1986

HAMEL, W. R.,* AND S. M. BABCOCK,* "Manipulator Technology: The Critical Element of Useful Autonomous "Working" Machines." (4.3)

1987 American Statistical Association Winter Conference, Orlando, FL, January 8-9, 1987

FROME, E. L., "Use of Poisson Regression Models in Statistical Data Analysis." (1.70)

Fourth Symposium on Space Nuclear Power Systems, Albuquerque, NM, January 12-16, 1987; Trans. CONF-870102-Summs., p. 161 (1987)

MOSES, D. L., AND R. D. McKNIGHT,* "The Role of Integral Experiments and Nuclear Cross Section Evaluations in Space Nuclear Reactor Design." (3.8)

Oral Presentation, University of Tennessee, Knoxville, TN, January 15, 1987

BOWMAN, K. O., "Statistical Inference — Computer Algorithmic Approach with Practical Examples." (1.53)

Workshop on Space Telerobotics, California Institute of Technology, Pasadena, CA, January 20-23, 1987

GOLDSTEIN, M.,* F. G. PIN, de SAUSSURE, G., AND C. R. WEISBIN, "3-D World Modeling with Updating Capability Based on Combinatorial Geometry." (4.60)

RAO, N. S. V.,* S. S. IYENGAR, AND C. R. WEISBIN, "On Autonomous Terrain Model Acquisition by a Mobile Robot." (4.41)

1987 WATtec Conference on Perspectives in Global Competitiveness, Quality, Productivity, and Innovation, Knoxville, TN, February 17-20, 1987

MASKEWITZ, B. F., "Nuclear Industry Quality, Productivity, and Innovation from the Perspective of an International Information Center." (5.9)

WEISBIN, C. R., "Sensor-Based Modeling, Learning, and Coping with Unscheduled Events." (4.42)

19th Symposium on the Interface of Computer Science and Statistics, Philadelphia, PA, March 8-11, 1987

OSTROUCHOV, G., "Parallel Computing on a Hypercube: An Overview of the Architecture and Some Applications." (1.94)

Defense Nuclear Agency Workshop on the LD₅₀ for Healthy Young Adults Actively Irradiated with Low-LET Whole-Body Radiation, Arlington, VA, March 9-10, 1987

MORRIS, M. D., AND T. D. JONES,* "Dose-Response Model Selection for Animal Studies and Prediction of Human Response Levels." (1.91)

RHOADES, W. A., "The Nagasaki Reinforced Concrete Building Dose Calculations." (3.54)

German Physical Society Nuclear Physics Meeting, Groningen City, Holland, March 23-27, 1987

BEER, H.,* AND R. L. MACKLIN, "A Stopwatch for the Time Duration of the s-Process Neutron Irradiations." (2.11)

American Nuclear Society International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, WA, March 29 - April 2, 1987; Proc. 1987

BABCOCK, S. M.,* W. R. HAMEL,* AND S. M. KILLOUGH,* "Advanced Manipulation for Autonomous Mobile Robots," p. 290. (4.1)

de SAUSSURE, G., D. W. KAIMER,* AND C. R. WEISBIN, "A Real-Time Expert System for the Control of Autonomous Robot Navigation in the Presence of Moving Obstacles," p. 298. (4.25)

EINSTEIN, J. R., J. BARHEN, AND D. JEFFERSON,* "Intelligent Operating Systems for Autonomous Robots: Real-Time Capabilities on a Hypercube Supercomputer," p. 127. (4.29)

1987 IEEE International Conference on Robotics and Automation, Raleigh, NC, March 30 - April 3, 1987; Proc. Vols. 1, 2, and 3 (1987)

GOLDSTEIN, M.,* F. G. PIN, G. de SAUSSURE, AND C. R. WEISBIN, "3-D World Modeling Based on Combinatorial Geometry for Autonomous Robot Navigation," Vol. 2, p. 727. (4.59)

RAO, N. S. V.,* S. S. IYENGAR,* C. C. JORGENSEN, AND C. R. WEISBIN, "On Terrain Acquisition by a Finite-Sized Mobile Robot in Plane," Vol. 3, p. 1314. (4.40)

Public forum talk, Concord College, Athens, WV, April 8, 1987

DICKENS, J. K., "Reactor Safety and the Status of Commercial Nuclear Energy in the U.S." (2.42)

Reliability '87 Conference, Birmingham, England, April 14-16, 1987

HAIRE, M. J.,* H. E. KNEE, J. J. MANNING, J. F. MANNESCHMIDT,* AND K. SETOGUCHI,* "An Examination of Maintenance Activities in Liquid Metal Facilities: An Analysis by the Centralized Reliability Data Organization (CREDO)" (3.99)

14th Energy Technology Conference and Exposition, Washington, DC, April 14-16, 1987

HICKS, E.,* J. V. CONOPASK,* P. MIHLMESTER,* D. B. REISTER, L. D. TROWERIDGE, AND F. G. PIN, "RAMSGAS: A Micro-Computer-Based World Gas Market Model." (4.77)

American Physical Society Meeting, Crystal City, VA, April 20-23, 1987; Proc. Bull. Am. Phys. Soc. 32(4) (1987)

CARLTON, R. F.,* R. R. WINTERS,* G. W. TWEED,* J. A. HARVEY, AND N. W. HILL,* " $^{187}\text{Os} + n$ s-Wave Mean Level Spacings and Strength Functions," p. 1110. (2.14)

American Nuclear Society Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987; Proc. Vols. 1 and 2 (1987)

ALSMILLER, F. S., R. G. ALSMILLER, JR., AND O. W. HERMANN,* "Low-Energy Particle Production and Residual Nuclei Production from High-Energy Hadron-Nucleus Collisions," Vol. 2, p. 444. (3.13)

ALSMILLER, R. G., JR., F. S. ALSMILLER, T. A. GABRIEL, AND O. W. HERMANN,* "Modifications of the High-Energy Transport Code (HETC) and Comparisons with Experimental Results," Vol. 2, p. 399. (3.14)

BROADHEAD, B. L.,* R. A. LILLIE, J. V. PACE, III,* AND D. G. CACUCI, "Sensitivity/Uncertainty Analysis for the Hiroshima Dosimetry Reevaluation Effort," Vol. 1, p. 149. (3.52)

FU, C. Y., AND D. T. INGERSOLL, "Group Structure and Weighting Function Effects on Neutron Penetration through Thick Sodium-Iron Shields," Vol. 1, p. 158. (3.5)

GABRIEL, T. A., AND B. L. BISHOP,* "Radiation Damage in Silicon Due to Albedo Neutrons Emitted from Hadronic Beam Dumps (Fe and U)," Vol. 2, p. 454. (3.18)

INGERSOLL, D. T., AND N. OHTANI,* "JASPER: A Joint U.S.-Japan Program of Experimental Shielding Research," Vol. 2, p. 3-6. (3.7)

JOHNSON, J. O., AND T. A. GABRIEL, "Verification of a Monte Carlo Code System for Analysis of Ionization Chamber Responses," Vol. 1, p. 110. (3.34)

LILLIE, R. A., B. L. BROADHEAD,* J. V. PACE, III,* AND D. G. CACUCI, "Sensitivity/Uncertainty Analysis for the Nagasaki Dosimetry Reevaluation Effort," Vol. 1, p. 139. (3.53)

PARKS, C. V.,* B. L. BROADHEAD,* R. W. ROUSSIN, J. C. GAUTHEY, S. N. CRAMER, AND B. L. KIRK, "Intercomparison of Cross-Section Libraries Used for Spent Fuel Cask Shielding Analysis," Vol. 2, p. 559. (5.7)

TRUBEY, D. K., AND Y. HARIMA,* "New Buildup Factor Data for Point Kernel Calculations," Vol. 2, p. 503. (5.2)

Oral presentation, Mathematics Department Seminar, Northern Illinois University, DeKalb, IL, April 24, 1987

WARD, R. C., "Mathematical Sciences Research at the Oak Ridge National Laboratory." (1.153)

Workshop on Design for Computer Experiments, Champaign, IL, April 27-29, 1987

MITCHELL, T. J., AND M. D. MORRIS, "A Bayesian Approach to the Design and Analysis of Computer Experiments." (1.83)

Seventh Symposium on the Training of Nuclear Facility Personnel, Orlando, FL, April 27-30, 1987

CARTER, R. J., AND C. R. BOVELL,* "Development of BWR and PWR Event Descriptions for Nuclear Facility Simulator Training." (3.88)

Energy Division Specialty Conference on Energy 87. Energy Solutions Today for the Nineties, American Society of Civil Engineers, Atlantic City, NJ, April 27-30, 1987; Proc. 1987

PIN, F. G., "Automated Sensitivity Analysis: New Tools for Modeling Complex Dynamic Systems," p. 305. (4.101)

International Topical Meeting on Advances in Reactor Physics, Mathematics, and Computation, Paris, France, April 27-30, 1987

AZMY, Y. Y., "Multidimensional Linear-Linear Nodal Transport Methods in Weighted Diamond Difference Form." (3.31)

Second International Conference on Supercomputing, Santa Clara, CA, May 3-8, 1987; Proc. Vols. 1 and 2 (1987)

BARHEN, J., J. R. EINSTEIN, AND C. C. JORGENSEN, "Advances in Concurrent Computation for Machine Intelligence and Robotics," Vol. 2, p. 84. (4.10)

NATO RSG5 Meeting, Portsmouth, England, May 11, 1987

MORRIS, M. D., "Notes on the Effect of Dose Uncertainty." (1.87)

MORRIS, M. D., AND T. D. JONES,* "A Comparison of Dose-Response Models for Death from Hematological Depression." (1.90)

MORRIS, M. D., AND T. D. JONES,* "Prediction of the Mortality Dose-Response Relationship in Man." (1.92)

Advanced Robotics Program Workshop on Manipulators, Sensors, and Steps Towards Mobility, Nuclear Research Center, Karlsruhe, Federal Republic of Germany, May 11-13, 1987

MANN, R. C., "Multi-Sensor Integration for a Mobile Robot Using Concurrent Computing." (4.52)

1987 Goddard Conference on Space Applications of Artificial Intelligence and Robotics, Greenbelt, MD, May 13-14, 1987

GOLDSTEIN, M.,* F. G. PIN, AND C. R. WEISBIN, "3-D World Modeling for a Mobile Robot." (4.63)

PARKER, L. E., AND F. G. PIN, "Dynamic Task Allocation for a Man-Machine Symbiotic System." (4.66)

SPIE Symposium on Infrared Sensors and Sensor Fusion, Orlando, FL, May 18-22, 1987

MANN, R. C., "Multi-Sensor Integration Using Concurrent Computing." (4.51)

Annual Conference of the American Association for Cancer Research, Atlanta, GA, May 20-23, 1987

MANSFIELD, B. K.,* J. K. SELKIRK,* AND R. C. MANN, "Expression of Cytoplasmic Proteins in Friend Erythroleukemia Cells Chemically-Induced to Undergo Terminal Erythroid Differentiation." (4.58)

9th International Conference on Noise in Physical Systems, Montreal (Quebec), Canada, May 25-29, 1987

DIFILIPPO, F. C., AND C. MARCH-LEUBA, "Noise Analysis of Interactive Fissile Systems Using the ^{252}Cf Neutron Source." (3.74)

PEREZ, R. B., F. C. DIFILIPPO, AND G. de SAUSSURE, "A Formalism for the Study of Stochastic Eigenvalue Problems." (3.76)

Sixth ASTM-EURATOM Symposium on Reactor Dosimetry, Jackson Hole, WY, May 31 - June 5, 1987

MAERKER, R. E., "Application of the LEPRICON Methodology to LWR Pressure Vessel Surveillance Dosimetry." (4.1*7)

Oral presentation, BETECH '87, Rio de Janeiro, Brazil, June 1987

GRAY, L. J., G. E. GILES,* AND J. S. BULLOCK,* "Progress on Boundary Element Techniques for Electroplating Simulation." (1.15)

1987 Summer Meeting of the American Nuclear Society, Dallas, TX, June 7-11, 1987; Trans. Am. Nucl. Soc. 54 (1987)

AZMY, Y. Y., "The Bilinear Nodal Transport Method in Weighted Diamond Difference Form," p. 187. (3.28)

AZMY, Y. Y., "A Nodal Integral Method for the Neutron Diffusion Equation in Cylindrical Geometry," p. 183. (3.29)

DIFILIPPO, F. C., "Source of Correlated Noise in Experiments Using a ^{252}Cf Source," p. 349. (3.73)

MACKLIN, ROGER L.,* R. B. PEREZ, G. De SAUSSURE, AND R. W. INGLE,* "High Resolution Measurement of the ^{238}U Neutron Capture Yield for Incident Neutron Energies Between 1 and 100 keV," p. 344. (2.16)

MARCH-LEUBA, C., J. MARCH-LEUBA,* AND F. C. DIFILIPPO, "Interpretation of Subcriticality Measurements with Strong Spatial Effects," p. 348. (3.75)

Free Boundary Problems: Theory and Applications International Colloquium, Irsee, Bavaria, West Germany, June 11-20, 1987

WILSON, D. G., "Phase Change Problems Governed by Partial Differential Equations of Non-Parabolic Type." (1.44)

IVth International Workshop on Nonlinear Evolution Equations and Dynamical Systems, Balaruc-les-Bains, June 11-25, 1987

CACUCI, D. G., R. B. PEREZ, AND V. PROTOPOPESCU, "Extending Green's Function Formalism to General Nonlinear Equations." (3.82)

Southern Regional Education Board/Southern Regional Committee on Statistics Summer Research Conference, Gallinburg, TN, June 14-19, 1987

BOWMAN, K. O., "Small Sample Properties of Statistics - Computer Algorithmic Approach." (1.51)

MORRIS, M. D., "A Sequential Experimental Design for Estimating a Scale Parameter from Quantal Life Testing Data." (1.86)

IEEE International Conference on Neural Networks, San Diego, CA, June 21-24, 1987

BARHEN, J., V. PROTOPOPESCU, N. TOOMARIAN, AND M. CLINARD,* "Concurrent Neuromorphic Algorithms for Optimization of the Computational Load of a Hypercube Supercomputer." (4.15)

GULATI, S.,* S. S. IYENGAR,* N. TOOMARIAN, V. PROTOPOPESCU, AND J. BARHEN, "Nonlinear Neural Network for Deterministic Scheduling." (4.19)

JORGENSEN, C. C., "Neural Network Representation of Sensor Graphs in Autonomous Robot Path Planning." (4.33)

Sixth International Association for Mathematics and Computers in Simulation Conference on Computer Methods for Partial Differential Equations, Lehigh University, Bethlehem, PA, June 23-26, 1987; Proc. (1987)

NG, E., S. THOMPSON, AND P. G. TUTTLE,* "Experiments with Method of Lines Solvers on a Shared Memory Parallel Computer," p. 161. (1.147)

Army Strategic Defense Command Meeting, Huntsville, AL, July 10, 1987

WEISBIN, C. R., "Robotics and Intelligent Systems Program." (4.127)

American Statistical Association 1987 Joint Statistical Meetings, San Francisco, CA, August 17-20, 1987

BOWMAN, K. O., L. R. SHENTON,* AND H. K. LAM,* "Simulation and Estimation Problems Associated with the 3-Parameter Gamma Density." (1.65)

MITCHELL, T. J., AND M. D. MORRIS, "A Bayesian Approach to the Design and Analysis of Computational Experiments." (1.83)

UPPULURI, V. R. R., "Prioritization Techniques Based on Stochastic Paired Comparisons." (1.101)

WRIGHT, T., "A Simple Method for Probability Proportional to Size (PPS) Sampling without Replacement Based on Ranks." (1.105)

EQUADIFF 87, International Conference on Differential Equations, Xanthi, Greece, August 24-28, 1987

ALEXIADES, V., "Void Formation in Solidification." (1.1)

Ninth Annual DOE Low-Level Radioactive Waste Management Conference, Denver, CO, August 25-27, 1987

PIN, F. G., AND E. M. OBLow, "Sensitivity Analysis of Predictive Models with an Automated Adjoint Generator." (4.103)

American Nuclear Society Topical Meeting on Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Snowbird, UT, August 31 - September 2, 1987

PIN, F. G., AND C. R. WEISBIN, "An Overview of AI Activities at the ORNL Center for Engineering Systems Advanced Research." (4.123)

9th International Boundary Element Conference, University of Stuttgart, Germany, August 31 - September 4, 1987

GRAY, L. J., AND G. E. GILES,* "Boundary Element Method for Heat Transfer Between Contacting Non-Conforming Surfaces." (1.14)

Specialists' Meeting on Data for Decay Heat Predictions, Studsvik, Sweden, September 7-10, 1987

DICKENS, J. K., "Review of New Integral Determinations of Decay Heat." (2.38)

46th Session of the International Statistical Institute, Tokyo, Japan, September 7-16, 1987

BOWMAN, K. O., AND L. R. SHENTON,* "Power Transformation of the Sample Kurtosis." (1.58)

UPPULURI, V. R. R., AND T. N. BHARGAVA,* "Measures of Diversity Based on Fuzzy Multinomial Distributions." (1.102)

WRIGHT, T., "An Empirical Investigation of the Use of Ranks in π ps Sampling." (1.106)

DOE/AECL Sensitivity and Uncertainty Conference, San Francisco, CA, September 9-14, 1987

WORLEY, B. A., E. M. OBLow, F. G. PIN, R. E. MAERKER, J. E. HORWEDEL,* R. Q. WRIGHT,* AND J. L. LUCIUS,* "Deterministic Methods for Sensitivity and Uncertainty Analysis in Large-Scale Computer Models." (4.109)

American Nuclear Society International Conference on Fast Breeder Systems: Experience Gained and Path to Economical Power Generation, Kennewick, WA, September 13-17, 1987

HUMPHRYS, B. L.,* M. J. HAIRE,* K. H. KOGER,* J. F. MANNESCHMIDT,* K. SETOGUCHI,* R. NAKAI,* AND Y. OKUBO,* "An Examination of Reliability Critical Items in Liquid Metal Reactors: An Analysis by the Centralized Reliability Data Organization (CREDO)." (3.100)

First International Association for Statistical Computing World Conference, Shizuoka, Japan, September 17-19, 1987

BOWMAN, K. O., AND L. R. SHENTON, "Statistical Inference — Computer Oriented Algorithmic Approach." (1.61)

Second Workshop on Design for Computer Experiments, Santa Fe, NM, September 21-23, 1987

MITCHELL, T. J., AND M. D. MORRIS, "A Bayesian Approach to the Design and Analysis of Computer Experiments." (1.83)

NOTE: The following meetings/seminars will be held after September 30, 1987. However, since the papers/abstracts were cleared through the Laboratory Records Department before September 30, 1987, they are being included in this report.

Oral Presentation, Department of Computer Science, Vanderbilt University, Nashville, TN, October 1, 1987

NG, E., "Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems." (1.145)

Workshop on Spatial Reasoning and Multi-Sensor Fusion, St. Charles, IL, October 5-7, 1987

GOLDSTEIN, M., F. G. PIN, AND C. R. WEISBIN, "3-D World Modeling with Object Recognition for a Mobile Robot." (4.61)

Applied and Computational Mathematics Program Annual Meeting, Washington, DC, October 5-8, 1987

PROTOPODESCU, V., "Combat Modeling with Partial Differential Equations." (3.77)

Mathematics Department Seminar, Northern Illinois University, Dekalb, IL, October 9, 1987

WILSON, D. G., "Applied Analysis Research, Consulting and Collaboration at the ORNL." (1.39)

35th SIAM Anniversary Meeting, Denver, CO, October 12-15, 1987

HEATH, M. T., "Parallel Matrix Computations on Hypercubes." (1.139)

NG, E., "Direct Solution of Sparse Linear Systems on Multiprocessors." (1.143)

Second International Symposium on Methodologies for Intelligent Systems, Charlotte, NC, October 14-17, 1987

PARKER, L. E., AND F. G. PIN, "A Methodology for Dynamic Task Allocation in a Man-Machine System." (4.65)

Gatlinburg X International Conference on Numerical Algebra, Fairfield Glade, TN, October 19-23, 1987

GEIST, G. A., AND E. NG, "A Partitioning Strategy for Sparse Matrix Factorization on Multiprocessors." (1.125)

HEATH, M. T., "Parallel Solution of Triangular Systems on Distributed-Memory Multiprocessors." (1.140)

NG, E., "Direct Solution of Sparse Nonsymmetric Linear Systems." (1.144)

ROMINE, C. H., AND G. A. GEIST, "LU Factorization Algorithms on Distributed-Memory Multiprocessor Architectures." (1.151)

Human Factors Society 31st Annual Meeting, New York, NY, October 19-23, 1987

SCHRYVER, J. C.,* AND H. E. KNEE, "Integrated Operated-Plant Process Modeling and Decision Support for Allocation of Function." (3.92)

Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21-23, 1987

MITCHELL, T. J., AND M. D. MORRIS, "A Bayesian Approach to the Design and Analysis of Computational Experiments." (1.83)

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TOOMARIAN, N., "Neuromorphic Algorithms for the Solution of the Traveling Salesman Problem on a Hypercube." (4.23)

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GOLDSTEIN, M.,* F. G. PIN, AND C. R. WEISBIN, "3-D World Modeling for an Autonomous Robot." (4.62)

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REISTER, D. B., "Oil Production in the United State," p. 130. (4.86)

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NG, E., "Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems." (1.145)

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