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Engineering Physics and Mathematics Division

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ENGINEERING PHYSICS AND MATHEMATICS DIVISION
PROGRESS REPORT
FOR PERIOD ENDING AUGUST 31, 1989

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 October 1, 1987 through August 31, 1989. Earlier reports in this series are identified on the previous page.

Coverage of our research is provided primarily through abstracts of journal articles, reports, and presentations. In addition, this progress report includes appendices which summarize publications, presentations, and other professional activities of the division staff members as well as identification of new staff members, guests, and students. Of necessity, this report tends to look back upon past progress. A look forward toward the slowly changing role and directions for the division is provided in the Long-Range Plan for the period 1987-1991, which was published in January 1988.

Unusual challenges strongly impacted the division's work during the period. The continued wait for restart of the Tower Shielding Facility (since March 1987) has delayed the joint U.S.-Japan reactor-shielding program JASPER. The overriding DOE-wide concern with real and possible environmental, safety, and health problems requires increasing resources (of both funds and staff time), which now significantly reduce research productivity. The impact is universal, but is greatly emphasized in experimental programs. The continued difficulties of the Mathematical Sciences Section with a remote location in an otherwise abandoned building which has peculiar environmental features should be eliminated in 1991 when a building now under contract should be completed.

The report is organized following the division of our research among four sections and an information center. The division organization chart, as of October 1, 1989, is included at the back of the report.

Mathematical Sciences. Activities in the mathematical sciences feature increased and broadened interactions with the University of Tennessee. Examples include the Numerical Linear Algebra Year and the establishment of the Advanced Computing Laboratory. The ACL is expected to be equipped with a multi-gigaflop parallel computer in FY90.

In collaboration with Cornell University, a fracture-analysis system, based upon a new boundary-element technique, was developed to make feasible efficient numerical simulation of crack propagation, even for multiple cracks.

Nuclear-Data Measurement and Evaluation. Nuclear-data activities are gradually reduced in the U.S. and in other countries. In this context, about 60% of the nuclear-data evaluations in the next major release of the U.S. Evaluated Nuclear Data File, Version VI came from our nuclear-data section. ORELA (the Oak Ridge Electron Linear Accelerator) continues as the prime nuclear-data facility in the world and as such it has seen recent collaboration with groups from Harwell (UK), The University of Vienna (Austria), Cadarache (France), and the National Institute of Science and Technology (formerly NBS). Uses other than nuclear data include ORNL condensed-matter studies and a new intense parasitic position beam. ORNL support has not developed for basing a free-electron laser at ORELA although this seems feasible for at least much of the spectral range of interest.

Intelligent Systems. Mobile robots have progressed to HERMES-III, with an on-board manipulator and improved on-board sensors and computers. Advances have continued in control algorithms for autonomous robots. Attention is turning to the use of intelligent robots for environmental remediation and waste management. Close cooperation is in place with four universities (Florida, Michigan, Tennessee, and Texas). Our human-factors specialists have joined this section with the goal of studying human-machine symbiosis in order to optimize the contributions of intelligent machines.

Nuclear Analysis and Shielding. Analysis continued for diverse nuclear systems. New applications emphasize the New Production Reactor, especially in its graphite-moderated version. SDI hypervelocity particle shielding studies have been completed. Deterministic combat models incorporated nonlinear behavior. A major effort is evolving from the application of high-energy physics analysis to detectors planned for the Superconducting Super Collider (SSC). This section will contribute substantially to a new specialized center for detector development which is expected to include participation from many ORNL divisions and from universities, especially in the southeastern U.S.

Engineering Physics Information Center. The work of the Technical Data Management Center was completed, after a decade of operation for the Nuclear Regulatory Commission. For the Radiation Shielding Information Center, international cooperation assumes increasing importance. In the earlier years of operation, much of the technology to be shared came from the U.S. (and especially ORNL). Now the contributions from other countries (especially France and Japan) have assumed a major position.

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Section 1

MATHEMATICAL SCIENCES

1.0. INTRODUCTION

R. C. Ward

Activities in the mathematical sciences during the report period continued to be divided in nearly 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 computer science, mathematics, and statistics.

Parallel computing remained the focus of our basic research program in computer science, again emphasizing the development of algorithms for efficiently solving important basic computational problems of science and engineering, especially matrix computations, on advanced computer architectures. In addition a new research project has been established with the objective of understanding and characterizing the actual behavior of parallel programs on distributed-memory architectures. The project addresses the analysis of realistic and complete application codes rather than computational kernels, test problems, or single mathematical routines. Some of the recent highlights from our basic and applied computer science research have been a new algorithm for tridiagonalizing a nonsymmetric matrix, an analysis of the effect of time constraints on scaled speed-up, a parallel code for studying electron correlations in high temperature superconductors, and the development of a software package to support parallel processing on a local area network of workstations, and sponsorship jointly with the University of Tennessee of a special year devoted to numerical linear algebra year with international visitors, lecturers, and workshops.

Research in mathematics during the reporting period emphasized moving boundary problems, especially phase change problems involving heat transfer, and modeling complex phenomena using vector and parallel supercomputers. A new research program in modeling environmental waste problems was initiated and is expected to be the future focal point of our mathematical research sponsored by the DOE Applied Mathematical Sciences Subprogram. Recent highlights of our mathematics research and collaboration have been the development of a new boundary element technique that reduces computational times by an order of magnitude for numerical simulation of phenomena involving single cracks and now makes feasible simulation of multiple crack geometries, the development of a code to simulate thermal energy storage for the NASA space station, the development of a parallel code for studying lepton pair production in relativistic heavy ion collisions, and the development of a fully vectorized code for simulating 3-dimensional moving boundary problems that involve void formation.

In statistics, our basic research focus has continued to be in the area of computational statistics and biostatistics. Some of the highlights include the development of an algorithm for use by computational scientists in the design and analysis of computer experiments, the development of a mathematical model that predicts hematopoietic response and associated probability of mortality during and following exposure to ionizing radiation, and the development of an algorithm for finding a small set of the best models from a very large number (typically thousands) of possible hierarchical models. Our applied, or collaborative, research has involved our statisticians with work in most of the ORNL divisions and major organizations in Martin Marietta Energy Systems. Examples to illustrate the diversity of this collaborative are quality control methods for detecting flaws in currency, reliability analysis of army helicopters, life testing of irradiated materials, and time series analysis and forecasting of river flow rates. T. J. Mitchell, a researcher in our Statistics Group, was honored as the 1988 Author of the Year by Energy Systems during their annual awards ceremony in May, 1989, for his paper co-authored with J. J. Beauchamp on

variable selection in linear regression. (This research was discussed in the division's last progress report.)

Our Research Computing Facility has been upgraded and renamed the Advanced Computing Laboratory (ACL) to better reflect its computing environment, which now consists of individual workstations on a local area network with various compute, network, file, and print servers. Also, the Computer Science Department at the University of Tennessee - Knoxville (UTK) has joined us in support of the ACL. Our Intel iPSC has been replaced by an Intel iPSC/2 with 64 processors and 4 MBytes of memory per processor, our Sequent has been upgraded to 12 processors with 16 MBytes of shared memory, an Ncube/4 with 16 processors and 8 MBytes of aggregate memory has been purchased, and our DEC VAX 11/780 has been upgraded to an 11/785. Work is currently in progress to procure a multi-gigaflop research parallel computer during FY90 for use on some of ORNL's "grand challenges." A dedicated T1 communications link has been installed to connect our ACL with the Computer Science Department at UTK to facilitate their access to our computers and to provide ORNL a connection to SURAnet, the southeastern regional network of NSFnet.

COMPUTER SCIENCE

General Parallel Computing

1.1

A REMOTE HOST FACILITY FOR INTEL HYPERCUBES

T. H. Dunigan

(Abstract of ORNL/TM-11068, April 1989)

The structure and use of a remote host facility for controlling application programs on an Intel hypercube are described. The facility permits an alternate UNIX host, such as a graphics workstation or supercomputer, connected by a TCP/IP network to the Intel cube manager processor to communicate with application programs running on the hypercube nodes. The facility supports both C and FORTRAN applications.

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

1.2

PERFORMANCE OF A SECOND GENERATION HYPERCUBE

T. H. Dunigan

(Abstract of ORNL/TM-10881, November 1988)

The performance of four 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/1 hypercube, the Ncube hypercube, and the second generation Intel iPSC/2 hypercube.

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

1.3

HYPERCUBE SIMULATION ON A LOCAL AREA NETWORK

T. H. Dunigan

(Abstract of ORNL/TM-10685, November 1988)

We describe the structure and use of a distributed computing environment based on a hypercube programming model that runs on most UNIX (trademark of AT&T) systems with TCP/IP network support. The package 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 simulated by a collection of computers on a local area network. Each node of the simulated hypercube is a work station on the network. 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.

1.4

A PARALLEL DECOMPOSITION ALGORITHM FOR STAIRCASE LINEAR PROGRAMS

R. Entriken*

(Abstract of ORNL/TM-11011, December 1988)

As part of an extended research project on the parallel decomposition of linear programs, a parallel algorithm for Staircase Linear Programs was designed and implemented. This class of problems encompasses a large range of planning problems and when decomposed has simple subproblem formulations and communication patterns. This makes its solution a manageable step toward our eventual goal of producing a general code that automatically exploits problem structures of various forms.

The results presented here were derived from an implementation for a Sequent Balance 8000 shared-memory multiprocessor. The algorithm itself is message-based but can run on either shared- or distributed-memory parallel computers.

A simple diet planning problem is used to demonstrate the principles of the algorithm's development and performance. When applied to this problem, the parallel decomposition algorithm shows promise relative to present serial optimization codes. The nonlinear optimization code MINOS 5.1 is used both as a basis for comparison and as a generic subproblem solver. The greatest room for speedup is in exploiting problem structures. The results show that decomposition can improve efficiency even with a single processor. Examples are given where multiple processors lead to still greater efficiency.

Research sponsored by the Electric Power Research Institute; by the U.S. Air Force Office of Scientific Research; by the U.S. Department of Energy; by the National Security Agency; by the National Science Foundation; by the Science Alliance Program of the State of Tennessee; and by the Department of Operations Research at Stanford University.

*Stanford University, Stanford, CA.

1.5

HYPERCUBE MULTIPROCESSORS: WHAT THEY ARE AND HOW TO USE THEM

G. A. Geist

(Abstract of oral presentation presented at the University of Florida, Gainesville, FL, March 15-16, 1988)

This talk discussed the hypercube architecture and the present commercial implementations by NCUBE and Intel. It also addressed the effects of different data mappings onto the processors and the different communication patterns which develop in the network. Finally, good and bad methods of coding communication routines will be discussed.

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

1.6

A MACHINE-INDEPENDENT COMMUNICATION LIBRARY

G. A. Geist M. T. Heath
B. W. Peyton P. H. Worley

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989)

In this report we describe a library of routines that enables the development of portable parallel programs. The library is designed primarily to provide portable communication primitives and related system calls for distributed-memory architecture. The package need not be limited to such machines, however, and we expect that the message-passing paradigm on which the library is based will also be useful on other parallel architectures for which data locality is an important performance consideration.

The library also provides portable routines to perform certain widely-used, high-level communication operations, such as global broadcast and global sum. Their inclusion frees users from having to develop these commonly needed capabilities or to modify them to run on different machines. Finally, the library provides an execution tracing facility that can be used to monitor performance or to aid in debugging.

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

1.7

PARALLEL COMPUTING

M. T. Heath

(Abstract of article in the *Oak Ridge*, Sunday, August 6, 1989)

Parallel computing, in which many computers are used simultaneously to solve a single problem, is one of the most significant new trends in computer technology. The fastest supercomputers available today, as well as new generations of supercomputers now being designed, all gain much of their fantastic speed by exploiting various types of parallelism. Moreover, the direction of this trend is toward even higher degrees of parallelism using larger and larger numbers of computer processors.

This article gives elementary examples of how parallelism can be exploited, discusses the implications of parallelism for scientific computing, and illustrates ORNL's role in developing and using parallel computing technology.

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

1.8

PARALLEL COMPUTING: PERSPECTIVES AND PROSPECTS

M. T. Heath

(Abstract of book chapter in *Opportunities and Constraints of Parallel Computing* (in press))

The trend toward parallel processing is driven by both scientific and economic factors. At the high end of the performance range, parallelism is the only answer to the fundamental limits on computational speed that are being rapidly approached by today's supercomputers. In the lower and middle performance ranges, parallel architectures assembled from commodity parts, such as microprocessors and memory chips, provide the most cost effective systems. These trends are mutually supportive, as the lessons learned and software developed are transferred across systems.

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

1.9

HYPERCUBE APPLICATIONS AT OAK RIDGE NATIONAL LABORATORY

M. T. Heath

(Abstract of oral presentation presented at the 1988 ACM Symposium on Parallel Programming, Yale University, New Haven, CT, July 20, 1988)

To determine the viability of hypercube architectures for solving a broad spectrum of computational problems typically arising at Oak Ridge National Laboratory, a representative set of applications was chosen for implementation on a hypercube. The projects included finite element fracture analysis, cascade simulation, geochemical contaminant transport, image analysis, molecu-

lar dynamics of polymers, density functional theory, and nonlinear magnetohydrodynamics. Each project was a collaborative effort of scientists and engineers from the discipline in which the problem arose and experienced hypercube users from a parallel computing research group. Results of each of these projects and an overall summary are included in this report.

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

1.10

HYPERCUBES

M. T. Heath

(Abstract of oral presentation presented at the Conference on Computational Atomic and Nuclear Physics at One Gigaflop, Oak Ridge, TN, April 15, 1988)

This talk presented an overview of hypercube multiprocessor architectures and their use in scientific computing.

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

1.11

LIMITS TO PARALLELISM

M. T. Heath

(Abstract of oral presentation presented at the IBM Workshop on Parallel Computing, San Jose, CA, December 4-7, 1988)

We present brief remarks on the concepts of scaled speedup and the limits to parallelism implied by Amdahl's Law. It is well known that for a fixed size problem, efficiency declines as more processors are used. We point out that for many important problem classes, a similar effect results from a fixed limit on execution time (i.e., as the number of processors grows, the problem size cannot grow fast enough to offset the efficiency decline and still meet the overall bound on execution time).

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

1.12

ONCE AGAIN, AMDAHL'S LAW**M. T. Heath P. H. Worley**

[Abstract of *Comm. Assoc. Comput. Mach.* 32/2, 262-263 (February 1989)]

We review Amdahl's Law governing multiprocessor speedup in light of recently reported experience with massively parallel multiprocessors. We consider the interpretation of Amdahl's Law for problems of fixed size or fixed execution time, and note that in either case efficiency is ultimately limited. These results are not in conflict with the favorable experience that has been reported, since high speedups and efficiencies are attainable for sufficiently large problems and execution times.

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

1.13

**MULTIPROGRAMMING A
DISTRIBUTED-MEMORY
MULTIPROCESSOR****M. R. Leuze L. W. Dowdy*
K. H. Park***

[Abstract of ORNL/TM-11064, January 1989; also *Concurrency Practice and Experience* 1, 19-33 (1989)]

The development of computing systems with large numbers of processors has been motivated primarily by the need to solve large, complex problems more quickly than is possible with uniprocessor systems. Traditionally, multiprocessor systems have been uniprogrammed, i.e., dedicated to the execution of a single set of related processes, since this approach provides the fastest response for an individual program once it begins execution. However, if the goal of a multiprocessor system is to minimize *average* response time or to maximize throughput, then multiprogramming must be considered.

In this paper, a model of a simple multiprocessor system with a two-program workload is reviewed; the model is then applied to an Intel iPSC/2 hypercube multiprocessor with a workload consisting of parallel wavefront algorithms for solving triangular systems of linear equations. Throughputs predicted by the model are compared with throughputs obtained experimentally from an ac-

tual system. The results provide validation for the model and indicate that significant performance improvements for multiprocessor systems are possible through multiprogramming.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE, Office of Energy Research and by the Alexander von Humboldt Foundation.

*Vanderbilt University, Nashville, TN.

1.14

**A BIBLIOGRAPHY ON PARALLEL
AND VECTOR NUMERICAL
ALGORITHMS****J. M. Ortega* R. G. Voigt†
C. H. Romaine**

(Abstract of ORNL/TM-10998, January 1989)

This technical report contains a bibliography of the current and past research papers dealing with numerical algorithms on both parallel and vector computers.

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

*University of Virginia, Charlottesville, VA.

†NASA Langley Research Ctr., Hampton, VA.

1.15

**A THEORETICAL INVESTIGATION OF
A PARALLEL GENETIC ALGORITHM****C. C. Pettey* M. R. Leuze**

[Abstract of paper presented at the Third International Conference on Genetic Algorithms, Fairfax, VA, June 4-7, 1989; Proc. 398-405, J. D. Schaffer, Ed., Morgan Kaufmann Publishers Inc., San Mateo, CA (1989)]

In the past few years the limitations of uniprocessor computing systems and the increasing availability of multiprocessors have led to investigations of parallel genetic algorithms. One algorithm in particular, called PGA, consists of a set of communicating sequential genetic algorithms. This paper includes an investigation of the theoretical allocation of trials to schemata by PGA's in general and by a particular PGA (which performs communication in a uniformly random manner)

along with an experimental validation of an assumption made in the theoretical investigation.

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

*Vanderbilt University, Nashville, TN.

1.16

OVERVIEW OF ARCHITECTURES AND APPLICATIONS IN PARALLEL PROCESSING

C. H. Romine

(Abstract of oral presentation presented at the Army Survey on High Performance Computing, Washington, DC, February 23-24, 1989)

In this talk, we survey the state of the art in parallel processing, with emphasis on both architectures and applications. A general discussion of universal topics in parallel processing will include classification of architectures (using Flynn's taxonomy), methods for evaluating performance, and general guidelines for identifying potential parallelism in existing application codes. This will be followed by a survey of some of the existing machines that exemplify each class of architecture, and a discussion of the advantages/disadvantages of each type of machine. Peak performance figures will be given for machines that are capable of supercomputer-class performance on problems in scientific computing. Finally, an overview of possible future developments in parallel processing will be given.

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

1.17

THE EVOLUTION OF MULTIPROCESSING

C. H. Romine

(Abstract of oral presentation presented at North Carolina State University as part of the ORAU Visiting Lecture Series, Raleigh/Durham, NC, September 12, 1988)

In order to circumvent the inherent limitations on the speed of a conventional "von Neumann" type of computer, machines are being designed that will solve problems by using multiple processing units. The evolution of working multiprocessors can be traced back to the Illiac IV, which was put into operation in 1972 at NASA's Ames Research Center. Since then, a large number of multiprocessors have been designed and/or built, including the Denelcor HEP, the ICL DAP, the Cosmic Cube at Cal. Tech., the TRAC at the University of Texas, Cm* at Carnegie-Mellon University, ZMOB at the University of Maryland, and the MPP at NASA's Goddard Space Flight Center. More recently, vendors such as Intel, NCUBE, Ametek, Floating Point Systems, and Thinking Machines Corporation have introduced new multiprocessor computers into the marketplace.

This talk will cover the history of multiprocessing, describing the advantages and disadvantages of each type of multiprocessor. The focus will be the application of multiprocessors to numerical algorithms, but only a limited knowledge of numerical analysis is required.

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

Dense Matrix Computations

1.18

QR FACTORIZATION OF A DENSE MATRIX ON A HYPERCUBE MULTIPROCESSOR

E. Chu* A. George

(Abstract of ORNL/TM-10691, February 1988)

In this article we describe a new algorithm for computing the QR factorization of a rectangular matrix on a hypercube multiprocessor. The scheme involves the embedding of a two-dimensional grid in the hypercube network. We employ a global communication scheme which uses redundant computation to maintain data proxim-

ity, and the mapping strategy is such that for a fixed number of processors the processor idle time is small and either constant or grows linearly with the dimension of the matrix. A complexity analysis tells us what the aspect ratio of the embedded grid should be in terms of the shape of the matrix and the relative speeds of communication and computation. Numerical experiments performed on an Intel Hypercube multiprocessor support the theoretical results.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research; by Canadian Natural Sciences and Engineering Research Council; and by Science Alliance, University of Tennessee.

*University of Waterloo, Waterloo, Ontario, Canada.

1.19

REDUCTION OF A GENERAL MATRIX TO TRIDIAGONAL FORM

G. A. Geist

[Abstract of *SIAM Journal on Matrix Analysis and Applications* (in press); also ORNL/TM-10991, March 1989]

This report reviews recent research in finding eigenvalues of general matrices by first reducing the matrix to tridiagonal form and then applying LR iteration to this reduced form. The report also describes a new algorithm for solving this problem and shows why it is superior to the other approaches. While our results show the algorithm to be over three times faster than the EISPACK routines for finding eigenvalues, there are some matrices for which the algorithm fails. The report describes how to detect these matrices during the reduction process and how to attempt to proceed.

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

1.20

REDUCTION OF A GENERAL MATRIX TO TRIDIAGONAL FORM USING A HYPERCUBE MULTIPROCESSOR

G. A. Geist

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989)

Recently there has been a renewed interest in finding reliable methods of reducing general matrices to tridiagonal form. We have developed a serial reduction algorithm that appears to be very reliable in practice. In this paper we describe a parallel version of our algorithm, which has been implemented using a portable library developed at Oak Ridge National Laboratory (ORNL). The library allows the code to be portable across most commercial hypercubes.

The algorithm was developed as one step in the process of finding eigenvalues of nonsymmetric matrices. Our original parallel eigenvalue routines reduced the matrix to Hessenberg form and then applied QR iteration, but their performance was disappointing. Our new parallel routines reduce the matrix to tridiagonal form and then apply LR iteration. Using an iPSC/2, we compare the

performance of the new parallel routines with our previous parallel routines and show that the new routines are nearly an order of magnitude faster, allowing us to solve much larger problems than previously attempted.

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

1.21

FINDING EIGENVALUES AND EIGENVECTORS OF UNSYMMETRIC MATRICES USING A DISTRIBUTED-MEMORY MULTIPROCESSOR

G. A. Geist

(Abstract of oral presentation presented at the University of Tennessee, Knoxville, TN, April 11, 1988 and at the SIAM Conference on Applied Linear Algebra, Minneapolis, MN, July 11-15, 1988)

The best known method for finding the eigenvalues of dense unsymmetric matrices is the implicit double shift QR iteration. The complexity and large volume of communication required in this algorithm have hindered distributed-memory implementations. We will discuss several parallel implementations of this algorithm and their performance on the Intel iPSC. Recent advances in distributed-memory triangular solutions have been used to develop an algorithm for finding the eigenvectors of the matrix. While Amdahl's Law limits our present implementations of the QR iteration to a speedup of about 10, the performance of the eigenvector routines does not suffer from the same limitation.

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

1.22

THE UNSYMMETRIC EIGENVALUE: CAN HQR BE BEAT?

G. A. Geist

(Abstract of oral presentation presented at the American Mathematical Society Meeting, Lawrence, KS, October 29, 1988)

The HQR algorithm is a fast and robust method for finding eigenvalues of general real matrices. It applies the implicit double shift QR it-

eration to an upper Hessenberg matrix. This talk presented algorithms for reducing a general real matrix to tridiagonal form and then applying an implicit double shift LR iteration to this matrix. The methods that the algorithms employ to avoid or fix problems inherent in the approach were discussed and results were given.

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

1.23

FINDING EIGENVALUES AND EIGENVECTORS OF UNSYMMETRIC MATRICES USING A DISTRIBUTED-MEMORY MULTIPROCESSOR

G. A. Geist G. J. Davis*

[Abstract of ORNL/TM-10938, November 1988; also *Parallel Computing* (in press)]

Distributed-memory parallel algorithms for finding the eigenvalues and eigenvectors of a dense unsymmetric matrix are given. While several parallel algorithms have been developed for symmetric matrices, little work has been done on the unsymmetric case. Our parallel implementation proceeds in three major steps: reduction of the original matrix to Hessenberg form, application of the implicit double-shift QR algorithm to compute the eigenvalues, and back transformations to compute the eigenvectors. Several modifications to our parallel QR algorithm, including ring communication, pipelining and delayed updating are discussed and compared. Results and timings are given.

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

*Georgia State University, Atlanta, GA.

1.24

STABILIZED GAUSSIAN REDUCTION OF AN ARBITRARY MATRIX TO TRIDIAGONAL FORM

G. A. Geist A. Lu*
E. L. Wachspress*

(Abstract of ORNL/TM-11089, June 1989)

This report presents several ideas for improving the stability of Gaussian reduction of an arbitrary real matrix to tridiagonal form. First, we analyze conditions under which reduction algorithms

break down or become unstable. Second, we discuss how methods of threshold pivoting decrease the probability of these conditions occurring. Finally, we present new methods for recovering from breakdown when it does occur. The class of matrices that can be successfully reduced is significantly broadened by these new recovery algorithms.

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

*University of Tennessee, Knoxville, TN.

1.25

A PARTITIONING STRATEGY FOR PARALLEL SPARSE CHOLESKY FACTORIZATION

G. A. Geist E. Ng

(Abstract of ORNL/TM-10937, November 1988)

This report presents a solution to the problem of partitioning the work for sparse matrix factorization on a multiprocessor system. The goal of this partitioning strategy is to achieve load balancing and a high degree of concurrency among the processors while reducing the amount of processor-to-processor data communication. The task assignment strategy is based on the structure of the elimination tree for a given ordering and can be applied to arbitrarily unbalanced trees. This is important because popular fill-reducing ordering methods, such as the minimum degree algorithm, often produce unbalanced elimination trees. Results from the Intel iPSC/2 are presented for various finite-element problems using both nested dissection and minimum degree orderings.

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

1.26

LU FACTORIZATION ON DISTRIBUTED-MEMORY MULTIPROCESSORS

G. A. Geist C. H. Romine

(Abstract of oral presentation presented at the University of Florida, Gainesville, FL, March 15-16, 1988 and at the SIAM Parallel Processing Conference, Los Angeles, CA, December 1-4, 1987)

We discussed and compared two methods of improving the efficiency of LU factorization with

pivoting on distributed-memory multiprocessors. The first method uses a dynamic load balancing scheme to avoid work imbalances caused by pivoting. While this method increases the amount of communication required, it significantly reduces the execution time. The second method uses pipelining to mask the cost of pivoting. While pipelining complicates the algorithm, the execution time is slightly less than in the first method. Both algorithms have achieved efficiencies of 85% to 95% running on a 64 node iPSC hypercube.

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

1.27

FINDING EIGENVALUES AND EIGENVECTORS OF UNSYMMETRIC MATRICES USING A HYPERCUBE MULTIPROCESSOR

G. A. Geist R. C. Ward
G. J. Davis* R. E. Funderlic†

(Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988; Proc. Vol. II, pp. 1577-1582, Geoffrey Fox, Ed., May 1988)

Distributed-memory algorithms for finding the eigenvalues and eigenvectors of a dense unsymmetric matrix are given. While several parallel algorithms have been developed for symmetric systems, little work has been done on the unsymmetric case. Our parallel implementation proceeds in three major steps: reduction of the original matrix to Hessenberg form, application of the implicit double-shift QR algorithm to compute the eigenvalues, and back transformations to compute the eigenvectors. Several modifications to our parallel QR algorithm, including ring communication and pipelining, are discussed and compared. Results and timings are given.

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

*Georgia State University, Atlanta, GA.

†North Carolina State University, Raleigh, NC.

1.28

REGULARIZATION, GSVD AND TRUNCATED GSVD

P. C. Hansen*

(Abstract of ORNL/TM-10779, September 1988)

The generalized singular value decomposition (GSVD) is used to analyze two alternative methods for solving ill-posed problems: regularization in general form and truncated SVD. We give conditions in which suitable solutions can be found, discuss the perturbation theory, and show that the optimum regularization and truncation parameters can be computed via generalized cross-validation. Our analysis also sheds light on a particular method, based on a transformation to standard form, that avoids the numerical difficulties associated with computation of the GSVD.

Research sponsored by Danish Natural Science Research Council; U.S. Air Force, Office of Scientific Research; National Security Agency; National Science Foundation; Science Alliance Program of the State of Tennessee; and Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Copenhagen University Observatory, Copenhagen K, Denmark.

1.29

SOLUTION OF ILL-POSED PROBLEMS BY MEANS OF TRUNCATED SVD

P. C. Hansen*

(Abstract of ORNL/TM-10772, June 1988)

We investigate *Truncated SVD* (TSVD) solutions to ill-posed least squares problems involving matrices with ill-determined as well as well-determined numerical rank. If a *discrete Picard condition* is satisfied, then in *both cases* the truncation parameter can be chosen such that the TSVD solution is satisfactory. The appropriate truncation parameter, giving the optimal signal-to-noise ratio in the solution, is the minimizer of the generalized cross-validation function.

Research sponsored by Danish Natural Science Research Council; U.S. Air Force, Office of Scientific Research; National Security Agency; National Science Foundation; Science Alliance Program of the State of Tennessee; and Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

*Copenhagen University Observatory, Copenhagen K, Denmark.

1.30

PARALLEL TRIANGULAR SOLUTIONS AND DOWNDATING ON DISTRIBUTED-MEMORY MULTIPROCESSORS

M. T. Heath

(Abstract of oral presentation presented at the American Mathematical Society Conference, Knoxville, TN, March 25, 1988 and at the SIAM Conference on Applied Linear Algebra, Madison, WI, May 23-26, 1988)

In this talk we review recent progress in the development of efficient parallel algorithms for solving triangular systems and for updating or downdating triangular factorizations of matrices on distributed-memory multiprocessors. These two types of problems have a similar structure, so that algorithms for solving them are closely related. In both cases the granularity of the computations is rather fine and communication costs tend to dominate on message-passing multiprocessor systems such as a hypercube. We discuss several types of parallel algorithms for solving triangular systems, including modified cyclic algorithms, and apply them to an updating/downdating problem arising in signal processing. Empirical results obtained on commercial hypercubes are presented.

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

1.31

CHOLESKY DOWNDATING ON A HYPERCUBE

C. S. Henkel* M. T. Heath
R. J. Plemmons*

(Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988; Proc. Vol. II, pp. 1592-1598, Geoffrey Fox, Ed., May 1988)

Least squares modifications associated with the addition or deletion of data often involve updating or downdating the Cholesky factor of the observation matrix. We describe and compare parallel implementations for the hypercube of three methods for downdating the Cholesky factor: an orthogonal scheme, a hyperbolic scheme, and a hybrid scheme combining the first two. The computational complexities of these algorithms vary

significantly, but the parallel implementations of all three are similar in communication complexity to solving triangular systems. In computational tests on Intel iPSC hypercube, the algorithms performed similarly, suggesting a preference for the orthogonal method based on stability considerations. The methods we describe can be adapted to the parallel computation of general orthogonal factorizations, but our discussion is motivated by applications in signal processing using windowed recursive least squares filtering for near real-time computations.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research; by the Nuclear Engineering Fellowship Program; by the Air Force Office of Scientific Research; and by the National Science Foundation.

*North Carolina State University, Raleigh, NC.

1.32

THE INFLUENCE OF DISTRIBUTED- MEMORY ARCHITECTURES ON LINEAR ALGEBRA ALGORITHMS

C. H. Romine

(Abstract of oral presentation presented at the Computer Science Seminar, Gainesville, FL, March 30, 1989)

The effective use of distributed-memory multiprocessors involves many goals, including: maximizing concurrency of operations, balancing computational load, minimizing communication volume, and preserving data locality. These goals are seldom complementary, and hence the algorithm designer is usually forced to make trade-off decisions - for example, sacrificing some concurrency for a reduction in communication.

We describe a collection of multiprocessor algorithms on the hypercube for the solution of several standard problems in linear algebra. These algorithms illustrate the types of trade-offs that are made when trying to optimize overall performance on such machines. General guidelines for efficient distributed-memory computing will be presented.

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

1.33

ORTHOGONAL FACTORIZATION ON DISTRIBUTED-MEMORY MULTIPROCESSORS

C. H. Romine A. Pothen*

(Abstract of oral presentation presented at the American Mathematical Society Conference, Knoxville, TN, March 25, 1988)

We describe the design and implementation of several algorithms for orthogonal factorization on distributed-memory multiprocessors. We consider the effect that the data storage scheme has on the efficiency of orthogonal factorization. In particular, the way that the computation is organized depends upon the initial distribution of the

matrix to the processors. Our results will focus primarily on the hypercube topology, but are applicable to more general interconnection schemes. We investigate the effects of scaling and column pivoting on the parallel implementation. Factors such as the cost of column pivoting, the cost of communication, the effect of loop-unrolling, and the potential for pipelining are examined. These factors are used to model the performance of each of the factorization algorithms. Finally, the implementation of the orthogonal factorization algorithms on an Intel iPSC is described, along with the results obtained. These results are used to verify the models of execution time that were derived.

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

*Penn State University, University Park, PA.

Sparse Matrix Computations

1.34

SOLUTION OF SPARSE POSITIVE DEFINITE SYSTEMS ON A HYPERCUBE

A. George* M. T. Heath
J. Liu† E. Ng

[Abstract of ORNL/TM-10865, October 1988; also *J. Comp. Appl. Math.* 27, 129 (1989)]

The solution of large sparse positive definite systems of equations typically involves four steps: ordering, data structure set-up (symbolic factorization), numerical factorization, and triangular solution. This article describes how these four

phases are implemented on a hypercube multiprocessor. The role of elimination trees in the exploitation of sparsity and the identification of parallelism is explained, and pseudo-code algorithms are provided for some of the important algorithms. Numerical experiments run on an Intel iPSC multiprocessor are presented in order to provide some indication of the performance of the various algorithms.

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

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†York University, Downsview, Ontario, Canada.

1.35

COMMUNICATION RESULTS FOR PARALLEL SPARSE CHOLSKY FACTORIZATION ON A HYPERCUBE

A. George* J. Liu†
E. Ng

[Abstract of *Parallel Computing* 10, 287-298 (1989)]

We consider the problem of reducing data traffic among processor nodes during 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. This assignment is aimed at achieving load balancing among the processors and also reducing the amount of processor-to-processor data communication. An analysis of regular grid problems is presented, providing a bound on communication volume generated by the new strategy, and showing that the allocation scheme is optimal in the asymptotic sense. Some experimental results on the performance of this scheme are presented.

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

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†York University, Downsview, Ontario, Canada.

1.36

PARALLEL SPARSE GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING

A. George* E. Ng

[Abstract of ORNL/TM-10866, October 1988; also Workshop on Supercomputers and Large-Scale Optimization: Algorithms, Software, and Applications, University of Minnesota, Minneapolis, MN, May 16-18, 1988; *Proc. Special Volume of Annals of Operations Research*, Ben Rosen, Ed., North-Holland (in press)]

In this article we consider the factorization of a sparse nonsymmetric matrix using Gaussian elimination with partial pivoting on a multiprocessor having a globally-shared memory. The parallel algorithm makes use of a static data structure already developed. Some numerical experiments on a Sequent Balance 8000 are presented to demonstrate the efficiency of the parallel implementation.

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

*University of Waterloo, Waterloo, Ontario, Canada.

1.37

SOME ASPECTS OF THE SOLUTION OF SPARSE SYMMETRIC POSITIVE DEFINITE SYSTEMS ON HYPERCUBE MULTIPROCESSORS

A. George* E. Ng

(Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988)

The elimination tree of a sparse symmetric positive definite matrix A is a tree structure associated with the Cholesky factor L of A . This tree structure is a powerful tool in the solution of sparse symmetric positive definite systems. The elimination tree of L not only describes the structure of L , but it is also useful in analyzing the parallelism available in the parallel solution of such a system. In this talk both the theoretical and practical aspects of elimination trees in the solution of positive definite systems on hypercube multiprocessors are considered.

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

*University of Waterloo, Waterloo, Ontario, Canada.

1.38

SOME SHARED MEMORY IS DESIRABLE IN PARALLEL SPARSE MATRIX COMPUTATION

A. George* E. Ng

[Abstract of *ACM Sigsum Newsletter*, 23(2), 9-13 (1988)]

Over the past few years a number of algorithms for solving large sparse systems of equations on distributed-memory multiprocessors have been developed. In this article the authors point out that the properties of sparse matrix problems generally, along with the characteristics of these parallel algorithms for solving them, lead to inefficient use of memory. An example is presented to show that a relatively small amount of shared memory on an otherwise pure distributed-memory multiprocessor is very desirable when it is being used to execute these parallel algorithms.

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

*University of Waterloo, Waterloo, Ontario, Canada.

1.39

PARALLEL SOLUTION OF SPARSE LINEAR SYSTEMS

M. T. Heath

(Abstract of oral presentation presented at the University of Maryland, College Park, MD, September 29–30, 1988; at an Applications Group Meeting, University of Illinois at Urbana-Champaign, Urbana, IL, October 25, 1988; and at the State University, of New York, Buffalo, NY, November 11, 1988)

Various issues in the solution of large sparse systems of linear algebraic equations on parallel computer architectures were discussed. Parallel algorithms for the four major steps in solving a sparse positive definite linear system—ordering, symbolic factorization, numeric factorization, and triangular solution—were presented. Special emphasis to the role played by elimination trees in exploiting sparsity and identifying potential parallelism, and numerical results for both distributed- and shared-memory implementations were given.

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

1.40

PARALLEL SOLUTION OF SPARSE LINEAR SYSTEMS

M. T. Heath

(Abstract of oral presentation presented at NASA Ames Research Center, Moffett Field, CA, March 9, 1989)

We discuss various issues in the solution of large sparse systems of linear algebraic equations on parallel computer architectures. We present parallel algorithms for the four major steps in solving a sparse positive definite linear system: ordering, symbolic factorization, numeric factorization, and triangular solution. We give special emphasis to the role played by elimination trees in exploiting sparsity and identifying potential parallelism. We give numerical results for both distributed-memory and shared-memory implementations.

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

1.41

A FAST ALGORITHM FOR REORDERING SPARSE MATRICES FOR PARALLEL FACTORIZATION

J. G. Lewis* B. W. Peyton
A. Pothen†

[Abstract of ORNL/TM-11040, January 1989; also *SIAM J. Sci. Stat. Comput.* 10, 1146–1173 (1989)]

Jess and Kees (1982) introduced a method for ordering a sparse symmetric matrix A for efficient parallel factorization. The parallel ordering is computed in two steps. First, the matrix A is ordered by some fill-reducing ordering. Second, a parallel ordering of A is computed from the filled graph that results from factoring A using the initial fill-reducing ordering. Among all orderings whose fill lies in the filled graph, this parallel ordering achieves the minimum number of parallel steps in the factorization of A . Jess and Kees did not specify the implementation details of an algorithm for either step of this scheme. Liu and Mirzaian (1987) designed an algorithm implementing the second step, but it has time and space requirements higher than the cost of computing common fill-reducing orderings.

We present here a new fast algorithm that implements the parallel ordering step by exploiting the *clique tree* representation of a chordal graph. We succeed in reducing the cost of the parallel ordering step well below that of the fill-reducing step. Our algorithm has time and space complexity linear in the number of *compressed subscripts* for L , i.e., the sum of the sizes of the maximal cliques of the filled graph. Empirically we demonstrate running times nearly identical to Liu's heuristic Composite Rotations algorithm that approximates the minimum number of parallel steps.

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

*Boeing Computer Services, Seattle, WA.

†Pennsylvania State University, University Park, PA.

1.42

ON THE COMPLEXITY OF SOME SPARSE MATRIX FACTORIZATIONS

E. Ng

(Abstract of oral presentation presented at the American Mathematical Society Conference, Knoxville, TN, March 25, 1988)

Let A be an $n \times n$ matrix derived from a two-dimensional finite element mesh. If the matrix A 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 talk we show that the same complexity bounds can be attained when A is nonsymmetric and indefinite, and either Gaussian elimination with partial pivoting or orthogonal factorization is applied.

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

1.43

SOME IDEAS IN THE SOLUTION OF SPARSE LINEAR LEAST SQUARES PROBLEMS

E. Ng

(Abstract of oral presentation presented at the University of Tennessee, Knoxville, TN, February 29, 1988 and at Stanford University, Stanford, CA, March 31, 1988)

The problem of solving large sparse linear least squares problems is considered. The solution method is based on orthogonal factorizations. The data structures and an algorithm for computing the orthogonal decomposition will be presented. An attractive feature of the approach is that both the orthogonal transformations and the triangular factor are saved. Hence multiple least squares problems which have the same coefficient matrix but different right hand sides can be solved very efficiently. Techniques for handling rank-deficient problems will be described.

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

1.44

SPARSE PARTIAL PIVOTING USING STATIC STORAGE SCHEMES

E. Ng

(Abstract of oral presentation presented at the International Mathematics and Statistical Library, Houston, TX, July 7, 1989)

Consider the problem of solving a general sparse nonsymmetric system of linear equations. The solution process typically involves computing a triangular factorization of the coefficient matrix (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 this talk, we describe some of our 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.

1.45

PARALLEL DIRECT SOLUTION OF SPARSE LINEAR SYSTEMS

E. Ng

(Abstract of ORNL/TM-11045, January 1989; also paper presented at a Workshop on Parallel and Vector Computing, Austin, TX, October 17-18, 1988; Proc. *Parallel Supercomputing: Methods, Algorithms, and Applications*, pp. 157-176, G. F. Carey, Ed., John Wiley (1989))

In this paper the direct solution of sparse linear systems on multiprocessor systems is considered. Elimination trees are used as a tool for identifying and exploiting parallelism in the parallel numerical factorization of the coefficient matrix. Some open problems are described and results of some numerical experiments are provided.

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

1.46

A COMPARISON OF SOME METHODS FOR SOLVING SPARSE NONSYMMETRIC LINEAR SYSTEMS

E. Ng

(Abstract of oral presentation presented at the SIAM Symposium on Sparse Matrices, Gleneden Beach, OR, May 22-24, 1989)

In this talk we consider the solution of sparse nonsymmetric and nonsingular systems of linear equations using Gaussian elimination with some form of row and/or column pivoting to ensure numerical stability and to preserve sparsity. The cost of the triangular factorization, in terms of execution time and storage requirement, depends very much on the choice of the data structures and the design of algorithms that manipulate these data structures. In recent years, there has been much research on the design of efficient data structures and algorithms for sparse Gaussian elimination.

Using test problems from the Harwell-Boeing sparse matrix collection, we have performed a comprehensive comparison of various methods for solving sparse nonsymmetric systems. We present our findings in this talk.

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

1.47

A SCHEME FOR HANDLING RANK DEFICIENCY IN THE SOLUTION OF SPARSE LINEAR LEAST SQUARES PROBLEMS

E. Ng

(Abstract of ORNL/TM-10980, November 1988)

Recently we have presented several schemes for computing sparse orthogonal factorizations using static data structures are large enough to store both the orthogonal transformations and upper triangular factor explicitly. Thus, multiple least squares problems with the same observation matrix can be solved easily. However, in order to make use of the static data structures, the orthogonal factorization is computed without column interchanges. In this article we develop an algorithm that makes use of the resulting factorization to solve rank-deficient least squares problems. The techniques used are similar to those employed by Bjorck.

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

Differential Equations

1.48

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

S. Thompson

(Abstract of *ACM Trans. on Mathematical Software* (in press))

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.

1.49

EXPLICITLY PARALLEL ALGORITHMS FOR HYPERBOLIC PDES - A PROOF OF PRINCIPLE

P. H. Worley

(Abstract of paper presented at SIAM Annual Meeting, San Diego, CA, July 17-21, 1989)

We define a class of easily parallelized algorithms, *explicitly parallel algorithms* or EPAs, and show how to formulate them for specific model problems related to the numerical solution of hyperbolic PDEs in one-space dimension. We then compare their execution time to parallel implementations of good serial algorithms for the same problems. The execution time is estimated analytically and measured empirically on an Intel iPSC/2 hypercube multiprocessor, demonstrating

that the EPAs are the better parallel algorithms for both small grain and large grain parallel implementations.

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

1.50

THE EFFECT OF TIME CONSTRAINTS ON SCALED SPEED-UP

P. H. Worley

(Abstract of ORNL/TM-11031, January 1989)

Gustafson, Montry, and Benner introduced the concept of scaled speed-up to characterize the capabilities of distributed-memory MIMD multiprocessors. They argued that, for a fixed-size problem, the behavior of the speed-up of an algorithm as a function of the number of processors, the *speed-up curve*, can be too pessimistic a measure of a multiprocessor architecture. Instead, they measured the speed-up of algorithms when the size of the corresponding problem grew with the number of processors. They referred to the resulting function as the *scaled speed-up curve*.

The scaled speed-up curve is a function of how the size of the problem is allowed to grow. We demonstrate that allowing the size of a problem to grow to fill the available memory can produce dramatically different results from allowing the size of a problem to grow subject to satisfying an upper bound on the execution time. In particular, if a constraint on the execution time is enforced, then the scaled speed-up curve is often very similar to the speed-up curve for a fixed-size problem. We show that no more than 50 processors can be used efficiently for some common problems in scientific computation when using the current generation of distributed-memory multiprocessors. For other problems, we show that the scaled speed-up curve indicates that massively parallel computers will be useful even if the execution time is constrained. In all of the cases examined, a meaningful interpretation of the scaled speed-up curve depends on a constraint on the execution time.

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

1.51

LIMITS ON PARALLELISM IN THE NUMERICAL SOLUTION OF LINEAR PDES

P. H. Worley

(Abstract of ORNL/TM-10945, October 1988)

We consider approximating the solution of a linear scalar partial differential equation (PDE) at a single location in its problem domain. In previous work we described a lower bound on the amount of data required to satisfy an error bound for the approximation. Using this bound, we derive a lower bound on the parallel complexity of algorithms that approximate the solution. The lower bound is a linear function of $\log_2 \epsilon - 1$, where ϵ is an upper bound on the error. Thus, the parallel complexity increases as ϵ decreases, independent of the number of processors, the interconnection topology, and the algorithm used. We also describe how the lower bound changes when the interconnection network or the number of processors is specified.

Recent research has established that it is often possible to use a large number of processors efficiently when calculating the numerical solution of a PDE if the problem is sufficiently large. We argue that increasing the size of such a problem will usually come at the cost of increasing the execution time. We describe two examples verifying this conclusion, an algorithm-independent analysis of an elliptic PDE and an analysis of a specific algorithm for the approximation of a hyperbolic PDE.

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

1.52

LIMITS ON PARALLELISM IN THE NUMERICAL APPROXIMATION OF LINEAR PDES

P. H. Worley

(Abstract of oral presentation presented at the Conference on Numerical Solutions of Partial Differential Equations, Virginia Polytechnic Institute, Blacksburg, VA, September 24-27, 1988 and at the Research in Multiprocessing Special Interest Group/Numerical Analysis Special Interest Group Meeting, Anaheim, CA, October 18, 1988)

Amdahl's Law describes bounds on the efficiency of parallel algorithms for a fixed size problem as a function of the number of processors. It

has recently been argued that this is not a fair measure of the capabilities of a multiprocessor architecture. Instead, it has been proposed that the size of the problem be allowed to increase along with the number of processors, subject to the condition that the execution time does not also increase. If the problem to be solved is a linear scalar PDE, we show that is not generally possible to increase the size of the problem without increasing the execution time. The argument easily generalizes to systems of equations, and it is reasonable to assume that most nonlinear PDEs will behave in the same way.

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

1.53

INFORMATION REQUIREMENTS AND THE IMPLICATIONS FOR PARALLEL COMPUTATION

P. H. Worley

(Abstract of Ph.D. Thesis in Computer Science, Stanford University, Stanford, CA, 1987)

The best serial algorithms for numerically approximating the solution of a linear partial differential equation (PDE) exploit knowledge of the solution operator. This dissertation describes how the solution operator also influences the behavior of parallel algorithms.

Approximating the solution at a single location in the problem domain is considered. We derive a lower bound on the error in the approximation that is a function of the amount of data used and the smoothness of the data functions. From this we derive a lower bound on the parallel complexity of algorithms that approximate the solution. The lower bound on the parallel complexity is a logarithmic function of the reciprocal of an upper bound on the error. Thus, the parallel complexity increases as the error bound decreases, independent of the number of processors used. We also construct an algorithm whose parallel complexity is of this form, proving that the form of the bound is the best possible.

The execution time of parallel algorithms is a function of both the communication costs and the parallel complexity. We describe bounds on the communication costs of parallel algorithms that are functions of the distance between collaborating processors. If the interconnection network of a given multiprocessor is a d -dimensional grid, then we prove that the execution time for algorithms that approximate the solution is bounded from below by a negative power of the error bound. Thus, if the upper bound on the error is small, then the communication costs are the dominant constraints on the optimal performance.

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

MATHEMATICS

Phase Change Problems

1.54

EFFECT OF A VOID ON CYCLIC MELTING AND FREEZING OF AN ENCAPSULATED PCM

V. Alexiades

(Abstract of book chapter in *Multiphase Flow Heat and Mass Transfer*, ASME HTD-Vol. 109, pp. 17-20, R. K. Shak, Ed., American Society of Mechanical Engineers, New York (1989); also oral presentation presented at the 1989 National Heat Transfer Conference, Philadelphia, PA, August 6-9, 1989)

Melting and solidification processes are generally accompanied by changes in density. These induce movement in the PCM and complicate the phase-change process considerably. In latent heat energy storage systems being considered for the manned space station, solar energy will be used to melt an encapsulated PCM during the light part of the orbit and the heat will be withdrawn dur-

ing darkness to provide continuous power to an engine. One of the promising high temperature PCMs under study is germanium encapsulated in graphite. Liquid germanium is denser than solid, so on melting the reduction in volume results in the formation of a void (vapor bubble) somewhere in the container. Since the conductivity of vapor is much smaller than that of the other phases, the void acts as a thermal barrier, altering the thermal field and thus the phase-change process itself. During freezing, the solid expands and the void diminishes. We are primarily concerned with how the void affects the cyclic charge-discharge process.

Results of computational experiments are presented for the case of imposed flux boundary conditions over several charge-discharge cycles.

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

1.55

SHRINKAGE EFFECTS ON SOLIDIFICATION

V. Alexiades

(Abstract of paper presented at the 2nd International Conference on Trends in Welding Research, Gatlinburg, TN, May 14-18, 1989)

When solid is denser than liquid, the volume reduction upon solidification of an encapsulated material creates a void (vapor bubble), making the phase-change process considerably more complicated (since mass movement is induced). The void acts as a barrier to heat transfer (due to the very small conductivity of vapor), and we are interested on how this affects the solidification process. We construct a rather simple thermal model for solidification that accounts for the presence of growth of a void inside the cavity. Results of numerical simulations are presented as examples.

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

1.56

EQUILIBRIUM SIZE OF A SOLID NUCLEUS FORMING IN SUPERCOOLED LIQUID

V. Alexiades

(Abstract of a chapter in *Free Boundary Problems*, K.-H. Hoffmann and J. Sprekels, Eds., Longman (in press))

Given the initial temperature, pressure and volume of a supercooled liquid in which nucleation is assumed to have occurred, the final equilibrium size and state of the solid-interface-liquid system are determined on the basis of energy conservation and thermodynamic equilibrium, taking into account surface area, curvature and pressure effects.

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.

1.57

A WEAK FORMULATION FOR PHASE-CHANGE PROBLEMS WITH BULK MOVEMENT DUE TO UNEQUAL DENSITIES

V. Alexiades J. B. Drake

(Abstract of oral presentation to be given at a meeting on *Free Boundary Problems: Theory and Applications*, Center for Research Mathematics, Montreal, Canada, June 13-22, 1990)

When the densities of solid and liquid are different, a change of phase induces a volume change, forcing movement of the bulk phases. Conservation of total energy across the interface leads to a modified Stefan Condition which contains a term cubic in the interfacial speed. We present a weak formulation for the conservation of mass, momentum and energy and study numerically a 1-phase, 1-dimensional example.

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

1.58

A CONVECTIVE FLOW IN THE PRESENCE OF MELTING

J. B. Drake V. Alexiades

(Abstract of oral presentation to be given at a meeting on *Free Boundary Problems: Theory and Applications*, Center for Research Mathematics, Montreal, Canada, June 13-22, 1990)

A numerical method for solving heat conduction and fluid flow problems that involve phase changes is described. The complications arising from materials with different liquid and solid densities are discussed and approximations developed for Marangoni stress, curvature dependent pressure jumps and void movement. Applications to both 0-g and 1-g environments are discussed, and numerical results of a 3-D simulation involving void movement are presented.

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

1.59

CHANGING DOMAINS AND A SOLIDIFICATION PROBLEM WITH VOID

S. M. Lenhart D. G. Wilson

(Abstract of *Quarterly of Appl. Math.* (in press); also oral presentation presented at the Southeastern-Atlantic Regional Conference on Differential Equations, University of Georgia, Athens, GA, November 4-5, 1988)

We consider Laplace's equation posed in a region with a hole. The exact location and shape of this hole is not specified *a priori*. Dirichlet data are specified on the exterior boundary of the region and a Robin boundary condition holds on the edge of the hole. The problem represents a mathematical model of an equilibrium thermal state following a phase change process in which a denser solid has frozen out of its less dense liquid with the formation of a void. Since the solid is more dense than the liquid, the combined volume of frozen solid and remaining liquid is less than that of the initial liquid (which is assumed to have filled a finite container) and a vapor bubble or void results. Energy balance considerations impose two auxiliary conditions to be satisfied. We establish the existence of admissible holes, i.e. voids, for which a solution to the problem exists and, in addition, the existence of an admissible void with minimal circumference.

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

1.60

PARALLEL SOLUTIONS OF A 2-D PHASE CHANGE PROBLEM ON A HYPERCUBE

H. N. Narang* J. B. Drake

[Abstract of ORNL-6504, April 1989; also paper presented at the ACM Southeast Region 27th Annual Conference, Atlanta, GA, April 5, 1989; Proc. pp. 650-656 (1989)]

This report documents the model, algorithms, and results for a heat transfer problem with phase change simulated numerically on a hypercube parallel computer. The temperature and enthalpy distribution in a rectangular domain with first kind boundary conditions (temperature prescribed) is found as a function of time. The model involves a non-linear partial differential equation

with a constitutive relation between enthalpy and temperature. The solution to the system is obtained by finite difference approximation with both explicit and implicit methods. In the implicit case, a successive overrelaxation technique with red, black ordering is implemented. The efficiency of the explicit method is compared with that of the implicit method in a multiprocessor computing environment.

The design, development, and implementation of algorithms targeted INTEL's iPSC/2 hypercube involving up to 64 processors. The computational workload was uniformly divided among processors as far as possible by dividing the finite difference grid into several strips and assigning each strip to a processor.

The results, depicted in terms of tables, show the effect of relaxation parameter, and stepsize on the efficiency of the parallel algorithms. This is contrasted with the sequential algorithms.

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

*Tuskegee University, Tuskegee, AL.

1.61

SURVEY OF THE LITERATURE ON FRACTALS WITH POSSIBLE APPLICATIONS TO PHASE CHANGE PROCESSES

L. A. Renker* D. G. Wilson

(Abstract of ORNL/TM-10778, June 1988)

This report is a partial collection of the literature on fractals and how it applies to phase change processes, specifically solidification. Fractals can be used to model the dendrites that are formed at the interface between a liquid and a solid with restrictions because either dendrites or non-dendritic fractals may be formed by diffusion limited solidification, depending on the presence of crystalline anisotropy. This anisotropy causes the tips of the structure being formed to remain stable, leading to the formation of a dendrite, rather than splitting to form a non-dendritic fractal. An additional type of structure is found when electrodeposition is used to model solidification. The formation of this dense radial structure depends on the level of the voltage and the electrolyte concentration. These structures are formed at intermediate values where the crossover from non-dendritic

fractals to dendrites occurs. Non-dendritic fractals are formed at the lower values and dendrites are formed at the higher values. A comprehensive bibliography is included with this report.

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

*Baldwin-Wallace College, Berea, OH.

1.62

SIMDLA: A FORTRAN PROGRAM SIMULATING DIFFUSION-LIMITED AGGREGATION

L. A. Renker* D. G. Wilson

(Abstract of ORNL/TM-10876, August 1988)

This report documents a FORTRAN program designed to simulate the diffusion-limited aggregation of particles. Particles are released one at a time from a growing internal boundary on a grid of possible sites and allowed to walk randomly until either they stick to the growing cluster or walk off the grid. The user may specify the grid dimension, the number of particles to be added to the cluster, the location and size of the seed cluster, and the possible directions (up to eight) in which particles are allowed to move. The output is a list of the occupied cells after all particles have been added to the cluster. A graphics post processor creates pictures from this list.

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

*Baldwin-Wallace College, Berea, OH.

1.63

ITERATIVE SOLUTION OF A NONLINEAR SYSTEM ARISING IN PHASE CHANGE PROBLEMS

M. A. Williams* D. G. Wilson

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

We have investigated the relative merits of two iterative procedures for solving the mildly nonlinear equations arising from an implicit discretization of a three-dimensional Stefan problem. The two procedures are successive overrelaxation (SOR) and a modified preconditioned conjugate

gradient method (MPCG) developed especially for this problem. The algorithms were implemented on a Cray X-MP and vectorization was a major consideration. Although MPCG converged in fewer iterations, the SOR iterations were shorter and faster. Thus, SOR required less Cray X-MP execution time. Finally, we found SOR to be more robust than MPCG.

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

*Lehigh University, Bethlehem, PA.

1.64

IMPLICIT FINITE DIFFERENCE SCHEMES FOR PHASE CHANGE PROBLEMS

D. G. Wilson

(Abstract of oral presentation presented at the 3rd International Seminar on Free Boundary Problems and Their Applications, Universidad Nacional de Rosario, Rosario, Argentina, October 11-15, 1988)

C. M. Elliot has proposed an implicit discretization of the enthalpy formulation of phase change problems. The resulting mildly nonlinear, implicit equations must be solved for enthalpy and temperature fields simultaneously. We have used this scheme to model three-dimensional phase change processes in Cartesian and cylindrical polar coordinates including one that involved convection in the melt. In this talk we discuss our experience with this scheme applied to these problems. We have used Crank-Nicholson type finite difference approximations to the partial differential equations and a corresponding discrete version of the enthalpy temperature relation, and we have used a successive overrelaxation iteration scheme with red/black ordering to solve the nonlinear equations. The algorithms have been vectorized for rapid execution on the Cray X-MP supercomputer, and if time permits, we will discuss techniques used to do this.

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

1.65

CYCLIC MELTING AND FREEZING WITH VARIABLE DENSITY

D. G. Wilson

(Abstract of oral presentation presented at the 3rd International Seminar on Free Boundary Problems and Their Applications, Universidad Nacional de Rosario, Rosario, Argentina, October 11-15, 1988)

We discuss the mathematical model and its discrete formulation (but not the computational algorithms) used to model a high temperature phase change process in a hollow metal canister. The solid phase change material is more dense than the liquid, and the change in density on freezing creates a void and also induces convection in the melt. The complete problem includes cyclic melting and refreezing, fluid flow, and void formation and movement, as well as conductive and convective heat transfer in a three-dimensional setting. We discuss only the equations used to model the phase change process. These consist of a mildly nonlinear partial differential equation (for energy redistribution), coupled with a constitutive relation for energy and temperature. This constitutes an enthalpy formulation of the phase change problem. The partial differential equation contains a convective heat transfer term whose inclusion is new for phase change problems. The nonlinear discrete equations consist of a Crank-Nicholson type finite difference approximation to the partial differential equation and a discrete version of the enthalpy temperature relation.

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

1.66

AN IMPLICIT, FINITE DIFFERENCE, ENTHALPY SCHEME FOR PHASE CHANGE PROBLEMS

D. G. Wilson

(Abstract of oral presentation presented at the Southeast Atlantic Section of SIAM Meeting, University of Tennessee, Knoxville, TN, March 17-18, 1989)

We define the enthalpy formulation of phase change problems, present a one-dimensional example of an implicit finite difference discretization

of the formulation, and show how to solve the resulting mildly nonlinear equations for the enthalpy and temperature fields simultaneously using a "selective SOR" iteration recommended by C. M. Elliott.

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

1.67

CHANGING DOMAINS AND SOLIDIFICATION PROBLEMS WITH VOIDS

D. G. Wilson

(Abstract of oral presentation presented at the Institute for Mathematics and Its Applications, University of Minnesota, Minneapolis, MN, February 19, 1988)

For many years solidification processes have been modeled with the convenient assumption that the densities of the solid and liquid phases are equal. Underlying this assumption is the fond hope that even if there is a density change on freezing, its effect is negligible. Recently, we at ORNL have been confronted with problems in which a substantial density change accompanies freezing. While working with these problems we have reconsidered the validity of the assumption that small density changes are ignorable. We have come to the realization that even when the density change on freezing is small, its effect may not be ignorable. We are still struggling with the consequences of this realization. In this talk we present some of the problems that have brought us to reconsider the assumption, some consequences of abandoning it and some results obtained for problems posed without it.

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

1.68

**AN IMPLICIT, FINITE
DIFFERENCE ENTHALPY
SCHEME APPLIED TO A
MULTIDIMENSIONAL CYCLIC
MELTING AND FREEZING
PROBLEM WITH VARIABLE
DENSITY**

**D. G. Wilson J. B. Drake
R. E. Flanery**

(Abstract of oral presentation presented at a Colloquium of the Materials Department of the Argentina Atomic Energy Commission, Buenos Aires, Argentina, October 20, 1988)

We define the enthalpy formulation of phase change problems, give one-dimensional examples of explicit and implicit finite difference discretizations of the formulation, and show how to solve the mildly nonlinear equations of the implicit formulation for the enthalpy and temperature fields simultaneously. We then discuss the use of these methods to model a multidimensional cyclic melting and freezing problem, namely a high temperature phase change process occurring in a hollow metal canister. The solid phase change material is more dense than the liquid, and the change in density on freezing creates a void and also induces convection in the melt.

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

1.69

**PHASE CHANGE PROBLEMS
WITH A VOID**

**D. G. Wilson J. B. Drake
R. E. Flanery**

(Abstract of chapter in *Mathematics and Industrial Problems*, pp. 97-99, A. Friedman, Ed., Springer-Verlag, New York (1988))

It is intended that the manned space station satisfy a considerable portion of its power requirements with solar energy. The station will orbit the earth in about ninety minutes and spend about two thirds of each orbit in sunlight and about one third in the earth's shadow. It will be necessary to store thermal energy during the station's exposure to the sun and to retrieve it during the transit through the earth's shadow. The thermal energy

storage system considered consists of a solar collector lined with a hundred or more small metal canisters filled with a high temperature phase change material (PCM), lithium fluoride salt. The problem that we have addressed, whose solution will contribute to a stress analysis of the canisters and a prediction of the performance of the storage system, is the modeling of the thermal and fluid flows in a representative canister. There will be fluid flow in the liquid PCM, even in a microgravity environment, because there is a significant difference in density between solid and liquid lithium fluoride. This causes the formation of one or more voids on freezing and, of course, the disappearance of voids on remelting. A heat transfer fluid, an inert gas such as helium or neon, circulates through pipes that pass through the metal canisters and carries heat away to turbines, generators, etc. The continual melting and refreezing of the PCM smears out the delivery of the solar energy to the transfer fluid and hence to the heat engines beyond.

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

1.70

**SUPERCOMPUTER SIMULATION OF A
3-D MELTING/FREEZING PROCESS**

D. G. Wilson R. E. Flanery

(Abstract of oral presentation presented at the Air Force Office of Scientific Research, Washington, DC, March 1, 1989)

We discuss the mathematical and computational model used to simulate a high temperature phase change process in a hollow metal canister that is an integral component of a proposed thermal energy storage system for the manned space station. The solid phase change material is more dense than the liquid, and the change in density of freezing creates a void and also induces convection in the melt. The complete problem includes cyclic melting and refreezing, fluid flow, and void formation and movement, as well as conductive and convective heat transfer in a three-dimensional setting. We discuss in detail only the simulation of the phase change process. The governing equations are a mildly nonlinear partial differential equation (for energy redistribution), coupled with a constitutive relation between energy

and temperature. The partial differential equation contains a convective heat transfer term whose inclusion is new for phase change problems. The nonlinear discrete equations consist of a Crank-Nicholson type finite difference approximation to the partial differential equation and a discrete version of the energy/temperature relation. The implicit difference equations and the constitutive relation are solved simultaneously at each time step. A successive overrelaxation iteration scheme with red/black ordering is used to solve the nonlinear equations. The algorithms have been vectorized for rapid execution on the Cray X-MP supercomputer, and we discuss techniques used to do this.

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

1.71

MODELING CYCLIC MELTING AND REFREEZING IN A HOLLOW METAL CYLINDER

D. G. Wilson R. E. Flanery

(Abstract of ORNL-6497, September 1988)

This report documents the mathematical model and computational algorithms used in a pair of computer programs that do energy redis-

tribution calculations as part of a comprehensive simulation for thermal and structural analyses of one component of a thermal energy storage system for the manned space station. The complete problem includes cyclic melting and refreezing, fluid flow, and void formation and movement, as well as conductive and convective heat transfer in a three-dimensional setting. The problem is posed in a hollow, metal canister filled with a high temperature phase change material. The heat transfer equations discussed here consist of a pair of partial differential equations for energy transfer (one linear the other mildly nonlinear), coupled with a constitutive relation for energy and temperature. This constitutes a weak, "enthalpy" formulation of the phase change problem. The partial differential equations are approximated by a system of coupled Crank-Nicholson-type finite difference equations. These nonlinear, implicit equations are solved for enthalpy (energy content) and temperature fields simultaneously. A successive overrelaxation iteration scheme with red/black ordering is used to solve the nonlinear difference equations. The algorithms have been vectorized for rapid execution on the Cray X-MP supercomputer and techniques used to do this are discussed.

Research sponsored by NASA Advanced Solar Dynamics Program and Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research.

Applied Mathematics

1.72

PARALLEL IMPLEMENTATION OF THE BOUNDARY ELEMENT METHOD ON THE iPSC2 HYPERCUBE

J. B. Drake L. J. Gray

(Abstract of paper presented at the Second International Conference on Vector and Parallel Computing: Issues in Applied Research and Development, Tromsø, Norway, June 6-10, 1988)

In this paper, the issues associated with the parallel implementation of the boundary element method (BEM) on a hypercube will be addressed. The program for solving the three-dimensional Laplace equation is specifically adapted for electro-plating simulations; this application involves nonlinear boundary conditions and a time step iteration to follow the develop-

ment of the plated surface. As a consequence, the coefficient matrices of the potential and normal derivative values are formed separately and stored. A step of the algorithm is thus required to combine and rearrange the system of equations into the standard form $AX=B$. The matrix A is dense and non-symmetric and recent advances in the solution of such systems on a hypercube are employed. Estimates of the arithmetic complexity at each step of the algorithm and a model for the communication costs are used to study the parallel performance of the BEM; timing results are presented for an implementation on an Intel iPSC2/d6 hypercube. We conclude that the BEM is particularly well suited for parallel solution and can be implemented efficiently on a hypercube.

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

1.73

MHD CALCULATIONS ON A HYPERCUBE MULTIPROCESSOR

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

(Abstract of oral presentation presented at the Department of Physics, Eindhoven University of Technology, Eindhoven, The Netherlands, June 2, 1988 and at the National Institute of Plasma Physics, Utrecht, The Netherlands, June 3, 1988)

As part of an exploratory study of the suitability of hypercube multiprocessors for scientific computations, the nonlinear MHD code RSF was adapted for use on the 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. A parallel method for solving multiple tridiagonal systems was developed as part of the algorithm. Timing results are presented for a sample problem.

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

*Fusion Energy Division.

1.74

A CAREER AS A WORKING MATHEMATICIAN - WHAT IT'S LIKE TO DO IT FOR REAL

R. E. Flanery

(Abstract of oral presentation presented at the Annual Banquet of Youngstown State Chapter of Pi Mu Epsilon, Youngstown State University, Youngstown, OH, May 19, 1989)

A career as an applied mathematician requires more than a degree in mathematics. Modeling physical processes requires a working knowledge of an application area such as heat transfer or fluid flow. To simulate the physical process on a computer we first create a physical model approximating the actual physical process. This model is described using mathematical equations, and algorithms to solve these equations are then developed. This leads to a computer code for solving the algorithms. All of these stages can depend

to some degree on the type of computer which will be used for the simulation. In most cases a 'realistic' mathematical model requires a powerful computer. Supercomputers such as the CRAY X-MP, CRAY-2 or iPSC hypercube are required for very complex models. Therefore an applied mathematician must also have a good background in computer science.

In addition to the above topics I will discuss how being a mathematician at ORNL is different than being a mathematician at a university or in industry, some of the projects I have been involved with, and what I plan to be doing in the future.

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

1.75

MAGNETICALLY SUSPENDED CENTRIFUGE FOR STUDIES OF NONLINEAR PHENOMENA IN STRATIFIED FLUIDS: DEVELOPMENTAL ASPECTS

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

[Abstract of *Rev. Sci. Instrum.* 60(10), 3293 (1989)]

Design studies of a novel magnetically suspended centrifuge suggest that such a device would be useful for investigating the nonlinear dynamics of interfacial waves in a rotating two-phase liquid. In its final form, the apparatus would use magnetic bearings, a directly-driven rotor, precision temperature control, and vibration isolation. The mechanical noise in the magnetic suspension coil of a preliminary apparatus was measured to be 3 μm rms in a 5 kHz bandwidth. However, these vibrations were attenuated by an active differentiator to the point where there was no observable oscillation in a 183 gram suspended test mass.

Research sponsored by U.S. Department of Energy.

*University of Virginia, Charlottesville, VA.

†Radford University, Radford, VA.

‡Engineering Technology Division.

1.76

BOUNDARY ELEMENT METHOD FOR REGIONS WITH CRACKS

L. J. Gray

(Abstract of oral presentation presented at the Southeast Atlantic Section of SIAM Meeting, University of Tennessee, Knoxville, TN, March 17-18, 1989)

The standard boundary element technique for a region with a crack is to decompose the problem into two (or more) subregions without cracks. This is accomplished by adding internal surfaces connecting the crack to the outer boundary. These extra surfaces can substantially increase the cost (both human and computer) of performing the calculation. In addition, modeling problems with many small cracks (e.g., concrete) becomes virtually impossible.

A new boundary element approach to cracked regions has been developed. This method avoids internal surfaces by utilizing a hypersingular (two derivatives of the Green's function) integral equation on the crack surface. The singular integrals are shown to have a sensible value when treated as a limit from the interior. For evaluating these integrals however, the functional approximations on the crack surface must be differentiable; an algorithm for accomplishing this task will be discussed.

Computational results for two applications involving the three-dimensional Laplace equation will be presented. The first problem concerns the heat transfer between two contacting solids, and the second application is the modeling of an electroplating cell.

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

1.77

EVALUATION OF HYPERSINGULAR INTEGRALS IN THE BOUNDARY ELEMENT METHOD

L. J. Gray

(Abstract of *Computers and Mathematics with Applications* (in press))

A recently developed boundary element technique for analyzing regions with cracks requires the consideration of hypersingular integrals. Although these integrals can be evaluated analyti-

cally, they require that the functional representation at collocation points on the crack surface be *differentiable*. An algorithm which accomplishes this task for three-dimensional problems utilizing standard elements, is presented herein. The entire neighborhood of a singular point is used to define the polynomial approximation, and the coefficients are determined by means of the generalized inverse of a rectangular matrix.

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

1.78

NUMERICAL EXPERIMENTS WITH A BOUNDARY ELEMENT TECHNIQUE FOR CORNERS

L. J. Gray

(Abstract of paper presented at the Eleventh International Conference on Boundary Element Methods, Cambridge, MA, August 29-31, 1989; Proc. *Advances in Boundary Elements*, Vol. 1, pp. 243-251, C. A. Brebbia and J. J. Connor, Eds., Computational Mechanics Publications, Boston, MA (September 1989))

A method for handling regions with corners or discontinuous boundary data has been recently proposed by Mitra and Ingber. Using double nodes to represent the corner and an external collocation point to generate the necessary additional equation, this paper reported (for the most part successful) test results on a variety of two-dimensional problems. In this paper, an exactly solvable Laplace equation problem, posed in a region with reentrant and non-reentrant edges, has been employed to study the behavior of this algorithm in three dimensions. As boundary surface edges give rise to multiple corner points, this problem provides a challenging test for the proposed algorithm. Experiments using several sets of external collocation points indicate that this technique is not a reliable procedure in three dimensions, yielding answers that are sensitive to the location of external nodes.

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

1.79

BOUNDARY ELEMENT METHOD FOR REGIONS WITH THIN INTERNAL CAVITIES

L. J. Gray

[Abstract of *Engineering Analysis* (in press)]

A new boundary element technique for treating thin cavities is presented. This method treats the cavity as an infinitely thin slit, but does not utilize fictitious internal boundaries to subdivide the domain. A non-singular system of equations is obtained by constructing two equations for each node on the boundary of the slit: the standard boundary element equation and the normal derivative of this equation. Although derived for Laplace's equation (in three dimensions) and tested on electroplating problems, it is expected that the method can be applied in other areas, most notably crack problems in fracture mechanics.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Health and Environmental Research; by Y-12 Development Division; and by IBM Bergen Scientific Centre, Norway.

1.80

BOUNDARY ELEMENT METHOD FOR CONTACT HEAT TRANSFER

L. J. Gray A. L. Askew*
G. E. Giles†

[Abstract of paper presented at the European Boundary Element Meeting, Brussels, Belgium, May 8-10, 1988; Proc. pp. 3.21-3.36, J. L. Migeot, Ed., Universite-Libre de Bruxelles (1989)]

The (steady state) heat flow between two contacting solids is investigated utilizing an efficient new boundary element method for treating thin cavities. A significant advantage of this approach is that a (multidomain) decomposition of the region is avoided and the contact region remains an interior surface. Consequently, the discontinuous flux across the contact/non-contact boundary is not solved for directly, and no special provisions for the singularity are required. These fluxes can be accurately obtained after the boundary integral equation has been solved and all boundary values are known. Calculations for a circular contact region are presented, and the results are compared against a known analytic solution. Since previous

work on this method has only considered interior cavities and the contact gap is a 'surface crack,' the treatment of surface cracks will also be described.

Research sponsored by the Y-12 Development Division of Martin Marietta Energy Systems, Inc.

*Brown University, Providence, RI.

†Computing and Telecommunications Division.

1.81

APPLICATION OF THE THIN CAVITY METHOD TO SHIELD CALCULATIONS IN ELECTROPLATING

L. J. Gray G. E. Giles*

[Abstract of paper presented at the 10th Boundary Element Meeting, Southampton, United Kingdom, September 6-8, 1988; Proc. *Boundary Elements X Computational Mechanics*, Southampton, England (1988)]

In a computational model of an electroplating tank, a thin shield can be conveniently approximated as a zero-thickness 'crack'. A newly developed boundary element method for treating cracks is especially advantageous for treating complicated three-dimensional geometries, such as plating cell configurations. In particular, nonsmooth shields, i.e., wherein a normal direction is not everywhere defined on the surface, can occur in practical plating applications. This paper will describe a technique for handling non-smooth shields, and calculations for an actual plating configuration were presented.

Research sponsored by the Y-12 Development Division of Martin Marietta Energy Systems, Inc.

*Computing and Telecommunications Division.

1.82

ELECTROPLATING SIMULATION

L. J. Gray G. E. Giles*
J. Bullock, IV† P. McKenzie†

[Abstract of paper presented at the European Conference on Mathematics in Industry, Glasgow, Scotland, August 28-31, 1989]

A simulation of a three dimensional electroplating process which includes a model of the heat flow generated during the plating is presented. The steady state temperature distribution in the cell is coupled to the electric field through the non-

linear polarization (overvoltage) boundary conditions and the temperature dependence of the electrolyte conductivity. As the conductivity directly influences the deposition rate, variations due to temperature can have an impact on the shape of the plated part. The thermal and electrostatic problems are simultaneously solved using the boundary element method, and a simple iterative scheme is employed to satisfy the boundary conditions. A newly developed boundary element procedure for crack geometries is used to cope with the thin shielding present in the cell. Utilizing this technique, a computationally expensive and cumbersome multidomain decomposition of the region is avoided.

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

*Computing and Telecommunications Division.

†Y-12 Development Division.

1.83

BOUNDARY ELEMENT METHOD FOR REGIONS WITH THIN INTERNAL CAVITIES. II

L. J. Gray G. E. Giles*
M. W. Wendel*

[Abstract of *Engineering Analysis* (in press)]

The basic framework of a new boundary element method for the analysis of regions with cracks has been described in a previous paper. This technique is completely general and, unlike the multidomain approach, does not utilize fictitious internal boundaries to subdivide the domain. By means of example three-dimensional electroplating calculations, it will be shown that this method is a practical algorithm. In particular, these calculations will demonstrate that specialized Green's functions for symmetric regions can be incorporated into the method, and that porous cavities are easily handled.

Research sponsored by Computing and Telecommunications Division.

*Computing and Telecommunications Division.

1.84

HYPERSINGULAR INTEGRALS IN BOUNDARY ELEMENT FRACTURE ANALYSIS

L. J. Gray L. F. Martha*
A. R. Ingraffea*

[Abstract of *International Journal for Numerical Methods in Engineering* (in press)]

A new general purpose boundary element method for domains with cracks has been recently developed. This technique avoids the use of a multidomain decomposition by including an additional integral equation expressing the boundary condition on the crack. The principal requirement of this technique is the analytic determination of certain hypersingular integrals of the Green's function which arise from this equation. In order to establish the applicability of this method for fracture, these integrals are evaluated herein for the Kelvin solution of the three-dimensional Navier equations of linear elasticity.

Research sponsored by Applied Mathematical Sciences Research Program, U.S. DOE Office of Energy Research; by IBM Berger Scientific Centre; by the National Science Foundation; and by CNPq, a Brazilian Government Agency.

*Cornell University, Ithaca, New York.

1.85

APPLICATION OF ONSAGER'S RECIPROCITY RELATIONS TO INTERFACE MOTION DURING PHASE TRANSFORMATIONS

T. Kaplan* M. J. Aziz†
L. J. Gray

[Abstract of *J. Chem. Phys.* 90(2), 1133-1140 (1989)]

A number of theories have been developed for kinetics of steady-state interface motion during a phase transformation. One requirement of such theories is that they satisfy Onsager's reciprocity relations for coupled irreversible processes. We show how to apply Onsager's relations to a phase transformation at a moving planar interface in a two-component system. The appropriate pairs of thermodynamic forces and conjugate fluxes are determined and used to test two proposed theories

for interface motion during solidification of binary alloys. It is shown that the Continuous Growth Model "with solute drag" of Aziz and Kaplan is inconsistent with Onsager's relations, but the Continuous Growth Model "without solute drag" is consistent with Onsager's relations.

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

*Solid State Division.

†Harvard University, Cambridge, MA.

1.86

CURVILINEAR COORDINATES FITTED TO A DISTORTED ANNULAR REGION

W. F. Lawkins

(Abstract of paper presented at a Seminar at Old Dominion University, Department of Mechanical Engineering, Norfolk, VA, November 7, 1988)

Physical problems concerning interfaces separating two media, where the position and velocity of the interface are not known *a priori*, remain among the most useful and difficult to solve. Modern numerical methods for attacking such problems all involve one form or another of adaptive grid generation. One such class of methods is based on the use of curvilinear coordinate transformations such that the interface is parameterized by a fixed one of the coordinate lines. Such methods will be discussed and some recent research pertaining to distorted annular regions will be presented. Further, the algorithms used to make calculations were implemented on an Intel Hypercube (64-node distributed memory computer), and some aspects of that experience will also be discussed.

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

STATISTICS

Design and Analysis of Computational Experiments

1.87

COMPUTER EXPERIMENTS TO
OPTIMIZE A COMPRESSION
MOLD FILLING PROCESS

A. Church, Jr.* T. J. Mitchell

(Abstract of oral presentation presented at the Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3-5, 1988)

We describe an application of the use of computer experiments to construct a fast approximation to a computer model that simulates the compression molding of sheet molding compound (SMC) in the manufacture of an automobile hood. The model code obtains numerical solutions (using a finite element method) to the differential equations that govern the flow of the SMC as it fills the mold cavity. The main purpose of the code is to predict the position of the flow front during the modeling process. This is used in turn to determine whether "knot lines" will occur; these form when two flow fronts meet, causing a weakness in the molded part. By altering the shape and position of the "charge," the initial piece of SMC that is compressed during the process, the effects of knot lines can be reduced or eliminated. Given an executable version of the model code as a black box, we designed a 15-run computer experiment to predict the movement of the flow front as a function of the shape and position of the charge. The results of this experiment, the prediction methodology, and its effectiveness in optimizing the charge parameters will be discussed.

Research sponsored by U.S. Department of Energy.

*GenCorp, Akron, OH.

1.88

A BAYESIAN APPROACH TO THE
DESIGN AND ANALYSIS OF
COMPUTER EXPERIMENTSC. Currin* T. J. Mitchell
M. D. Morris D. Ylvisaker†

(Abstract of ORNL-6498, September 1988)

We consider the problem of designing and analyzing experiments for prediction of the function

$y(t), t \in T$, where y is evaluated by means of a computer code (typically by solving complicated equations that model a physical system), and T represents the domain of inputs to the code. We use a Bayesian approach, in which uncertainty about y is represented by a spatial stochastic process (random function); here we restrict attention to stationary Gaussian processes. The posterior mean function can be used as an interpolating function, with uncertainties given by the posterior standard deviations. Instead of completely specifying the prior process, we consider several families of priors and suggest some cross-validation methods for choosing one that performs relatively well on the function at hand. As a design criterion, we use the expected reduction in the entropy of the random vector $y(T^*)$, where $T^* \subset T$ is a given finite set of "sites" (input configurations) at which predictions are to be made. We describe an exchange algorithm for constructing designs that are optimal with respect to this criterion. To demonstrate the use of these design and analysis methods, several examples are given, including one experiment on a computer model of a thermal energy storage device and another on an integrated circuit simulator.

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

*Bryn Mawr College, Bryn Mawr, PA.

†University of California at Los Angeles, Los Angeles, CA.

1.89

SENSITIVITY AND UNCERTAINTY
ANALYSIS IN ENVIRONMENTAL
MODELS

D. J. Downing S. Bartell*

(Abstract of oral presentation presented at a Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3-5, 1988)

A description and objectives of an environmental model (FOAM) are introduced. The general definitions of uncertainty and sensitivity analysis are discussed and applied to the FOAM model. The ideas are extended to look at the model predictions through time.

Research sponsored by U.S. Department of Energy.

*Environmental Sciences Division.

1.90

A BAYESIAN APPROACH TO THE DESIGN AND ANALYSIS OF COMPUTATIONAL EXPERIMENTS

T. J. Mitchell M. D. Morris

[Abstract of paper presented at the 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21-23, 1988; Proc. pp. 49-51, E. J. Wegman, D. T. Gantz, and J. J. Miller, Eds., American Statistical Association, Alexandria, VA (1988)]

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 for each run. This paper centers on the problem of prediction (interpolation), the goal of which is to devise a design/analysis method which will provide predictions of model output for input 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. Here we use as a design optimality criterion the determinant of the posterior covariance matrix of the responses at the input configurations at which we want to make predictions. This requires maximization of the determinant of the prior covariance matrix of the responses at the design sites. We describe our computer algorithm for constructing optimal designs and give some examples of designs that it produces.

Research sponsored by U.S. Department of Energy.

1.91

COMPUTER CONSTRUCTION OF OPTIMAL DESIGNS FOR PREDICTION IN COMPUTER EXPERIMENTS

T. J. Mitchell M. D. Morris

(Abstract of oral presentation presented at the IBM Scientific Centre, Bergen, Norway, July 18, 1988; at the University of Augsburg, Augsburg, Germany, July 22, 1988)

We consider the problem of designing experiments for prediction of the function $y(x)$, where y is evaluated by means of a computer code (typically by solving complicated equations that model

a physical system), and x represents the inputs to the code. We use a Bayesian approach, in which uncertainty about y is represented by a random function, i.e., a spatial stochastic process. We formulate design criteria based on maximizing the expected reduction in the entropy of the random vector $y(S)$ where S is a given set of "sites" (input configurations) at which predictions are to be made. This talk will be concerned primarily with algorithms for constructing optimal designs in this setting using the entropy criterion.

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

1.92

EXISTENCE OF SMOOTHED STATIONARY PROCESSES ON AN INTERVAL

T. J. Mitchell M. D. Morris
D. Ylvisaker*

[Abstract of *Stochastic Processes* (in press)]

Necessary and sufficient conditions are given for there to exist a stationary process on an interval with a given stationary process as its k^{th} derivative. The condition involves the norm in the reproducing kernel space associated with the process sought as derivative. Some explicit results are obtained when working with the Ornstein-Uhlenbeck and the linear kernels. These latter facts are useful in an adaptive Bayesian modelling of computer experiments; some remarks are given about this type of analysis.

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

*University of California, Los Angeles, CA.

1.93

FACTORIAL SAMPLING PLANS FOR PRELIMINARY COMPUTATIONAL EXPERIMENTS

M. D. Morris

(Abstract of oral presentation presented at the 1989 Joint Statistical Meetings, Washington, DC, August 6-10, 1989)

A *computational model* is a representation of some physical system of interest, first expressed mathematically and then implemented in the form of a computer program; it may be viewed as a function of *inputs* which, when evaluated, pro-

duces *outputs*. In this paper, we are concerned with computational models which are deterministic, complicated enough so as to make classical mathematical analysis impractical, and which have a moderate to large number of inputs. We consider the problem of designing computational experiments to determine which inputs have important effects on an output. The proposed approach is based on classical sampling ideas, involves the use of one-factor-at-a-time experimental designs, and does not rely on assumptions such as the adequacy of a low-order polynomial as an approximation to the computational model, effect sparsity, or monotonicity of outputs with respect to inputs. Prediction of the function $y(x)$, where y is evaluated by means of a computer code (typically by solving complicated equations that model a physical system e.g., a chemical reaction), and x represents the inputs to the code (e.g., reaction rates). We use a Bayesian approach, in which uncertainty about y is represented by a random function, i.e., a spatial stochastic process. The posterior mean function can be used as an interpolating function, with uncertainties given by the posterior standard deviations. Designs are selected to minimize a measure of posterior uncertainty. The approach will be demonstrated using as examples (i) a computer model for the combustion of methane and (ii) a computer model that simulates the compression molding of sheet molding compound (SMC) in the manufacture of an automobile hood.

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

1.94

BAYESIAN DESIGN AND ANALYSIS OF COMPUTER EXPERIMENTS: USE OF DERIVATIVES IN SURFACE PREDICTION

M. D. Morris

(Abstract of oral presentation presented at a Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3-5, 1988)

This talk is on our continuing research in the area of "fast predictive approximation" of a computer model. Our earlier work on a Bayesian solution is expanded for the case in which the first derivatives of the output variable with respect to

some or all input variables are available. In addition to analysis (actual construction of the predictor based upon data collected from executions of the model), we discuss the use of Shannon's entropy as a tool in selecting optimal experimental designs.

Research sponsored by U.S. Department of Energy.

1.95

COMMENT ON: DESIGN AND ANALYSIS OF COMPUTER EXPERIMENTS

M. D. Morris

[Abstract of *Statistical Science* (in press)]

The authors have provided an interesting and readable account of a statistical approach to the problem of approximating an unknown, deterministic computer model. The approximation of unknown functions, of at least a few arguments, has received considerable attention in other specialty areas of mathematics, but is relatively new to statistics. A statistical approach brings a unique potential for dealing with uncertainty in the problem. In particular, it can lead to measures of quality for each prediction and a structure on which to base the design of efficient experiments. Techniques which are relevant for approximating computer models are particularly timely because the scientific and technical professions are quickly becoming reliant upon these as research tools. This manuscript reports some of the first serious efforts to make statistics relevant to these activities.

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

1.96

A BAYESIAN APPROACH TO THE DESIGN AND ANALYSIS OF COMPUTATIONAL EXPERIMENTS

M. D. Morris T. J. Mitchell

(Abstract of oral presentation presented at the First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25-28, 1988)

A statistical approach to the approximation of deterministic computational models will be dis-

cussed. We regard a computational model as a complicated function mapping input variables, from some meaningful domain, into output variables. Large-scale computational models are often prohibitively difficult to examine analytically and may require considerable computational resources for each evaluation. Hence, we seek a methodology for empirically formulating a "fast predictive approximation" of the model, along with design strategies which allow us to do this in an efficient manner.

Our approach to the problem is Bayesian, based upon the use of a stochastic process over the domain of the computational model. The talk will cover details of the prior processes we have used, a design criterion based upon expected entropy, and examples of designs and model approximations in some simple cases. Some speculations on the form of optimal designs and model approximations in certain limiting situations will also be discussed.

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

1.97

DESIGN AND ANALYSIS OF COMPUTER EXPERIMENTS

J. Sacks* W. J. Welch†
T. J. Mitchell H. P. Wynn‡

[Abstract of *Statistical Science* (in press)]

Many scientific phenomena are now investigated by complex computer models or codes. A

computer experiment is a number of runs of the code with various inputs. A unique feature of many computer experiments is that the output is deterministic — rerunning the code with the same inputs gives identical observations. Often, the codes are computationally expensive to run, and a common objective of an experiment is to fit a cheaper predictor to the data. Our approach is to model the deterministic output as the realization of a stochastic process, thereby providing a statistical basis for designing experiments (choosing the inputs) for the efficient prediction. With this model, estimates of uncertainty of predictions are also available. A number of applications are discussed, and we demonstrate the methodology with an example. The example illustrates the gains in efficiency possible relative to standard least squares estimation of a response surface.

Research sponsored by U.S. DOE and NSE DMS Office of Naval Research.

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†University of Waterloo, Waterloo, Ontario, Canada.

‡City University, London, England.

Computational Distribution Theory

1.98

MOMENT METHODS AND THE GRAM-CHARLIER TYPE A

K. O. Bowman L. R. Shenton*

(Abstract of paper presented at the 47th Session of the Internal Statistical Institute, Paris, France, August 29-September 6, 1989)

The joint efficiency of estimation by moments for a four-parameter Gram-Charlier density involves a ratio of covariance determinants. Each element in the maximum likelihood case involves an integral, the denominator of the integrand being a quartic. In a study that came out by one of the authors several years ago, these integrals were approximated by ratios of generalized continuant-determinants with non-zero elements in the diagonal, and s th super and sub diagonals, ($s =$

1,2,3,4), i.e., determinants of nine-diagonal arrays. The computational methods at the time depended entirely on pen and paper work with some assistance from mechanical calculators. Quadrature procedures at the time were regarded as too fragile and only to be used when error estimates were included.

Research sponsored by U.S. DOE

*University of Georgia, Athens, GA.

1.99

SOLUTIONS TO JOHNSON'S S_B AND S_U

K. O. Bowman L. R. Shenton*

[Abstract of *Commun. Statist.-Simula.* 17(2), 343 (1988)]

Simple iterative and exact solutions are described depending on symmetric percentage points

for the Johnson translation system of distributions. A condition is given for a zero skewness parameter.

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

*University of Georgia, Athens, GA.

1.100

PROPERTIES OF ESTIMATORS FOR THE GAMMA DISTRIBUTION

K. O. Bowman L. R. Shenton*

[Abstract of a book Vol. 89, Marcel Dekker, Inc., New York, NY (January 1988)]

This monograph studies the subject at points where traditional exclusive mathematical approaches leave off. It is a blend of numerical analysis which is computer oriented and directed at questions involving series and the information contained therein; it brings to light much that is problematical in remainders, especially when these appear to be well defined in an existentialist fashion. It is an account of attempts to grapple with early 20th century dedication to mathematical edifices with a slow intrusion of computational facilities. It should interest students, broadly defined, who like to see science at work and in the making.

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

*University of Georgia, Athens, GA.

1.101

S_B AND S_U DISTRIBUTION FITTED BY PERCENTILES: A GENERAL CRITERION

K. O. Bowman L. R. Shenton*

[Abstract of *Commun. Statist.-Simula.* 18(1), 1-13 (1989)]

A criterion is given to choose between Johnson's S_B and S_U when four percentiles are used. Also the algorithms provided make it possible to use the percentiles corresponding to the data provided, thus avoiding the intricacies of interpolation.

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

*University of Georgia, Athens, GA.

1.102

CONTINUED FRACTIONS AND ASYMPTOTIC SERIES IN APPLICATIONS: WITH SPECIAL REFERENCE TO PROBLEMS IN STATISTICS

K. O. Bowman L. R. Shenton*

[Preface of a book, Marcel Dekker, Inc., New York, NY (April 1989)]

This book is an account of the use of continued fractions and Padé sequences as tools in the interpretation of divergent or slowly convergent series occurring in theoretical statistics. In our early studies an obstacle we had to overcome concerned the process of developing Taylor power series for moments of statistics; for example, the expected value of the sample standard deviation from some defined population. Traditionally one or two low order terms sufficed, because later terms involved heavier and heavier algebra soon leaving behind the most ardent algebraist; the digital computer arriving in the 1950s had little impact for algorithmic approaches which were not generally highly regarded, existing in a somewhat ill-defined gray area. So higher order terms in series were not available and the era of largeness of sample size was born, and the reliance from time to time on the uncertainties defined in the order of magnitude symbols (little o, big O).

Also early in the present century, summation algorithms (or techniques) had few illustrations of divergent series, so a few classical cases received a lot of attention; many of them (by chance in the evolution of mathematical analysis) were such that the first few terms looked beguilingly "convergent" (the series part of $\ln \Gamma(x)$ for example, and the polygamma function series). So there appeared the notion of absolute error in stopping at a certain term being related to the first term omitted; whereas this rule is sometimes true, in general it has no basis.

Our treatment is partly mathematical but pivoted on computer oriented numerical analysis (or computer oriented algebra). The increased confidence in our main algorithm for the expectation of quotients of products of sample moments was the driving force for increased knowledge of summation processes for seemingly divergent Taylor series. The study, by no means complete, and no doubt involving unavoidable errors (hopefully few) has spanned more than two decades.

Let it be made clear that our development of the subject has been motivated by an attempt to clarify the interpretation of divergent series in practical situations. The classical theory of rational approximation is overloaded with myraids of specialized theorems — albeit of some interest, and exhibiting acute mathematical expertise. But very few of these theoretical excursions amount to increased insights into the mechanics of the structure of functions and corresponding approximating functions.

Multivariate situations are not considered for there are many outstanding problems in the univariate case. At the very least, we hope the reader will gain a new awareness of the many varieties of series and the corresponding summation problems.

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

*University of Georgia, Athens, GA.

1.103

SOME PROPERTIES OF A MOMENT ESTIMATOR FOR THE INDEX PARAMETER OF NEGATIVE BINOMIAL DISTRIBUTION

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

[Abstract of paper published in Proc. of the 1988 Joint Statistical Meetings, pp. 365–367, New Orleans, LA, August 22–25, 1988 (1988)]

Taking the mean of the negative binomial to be $kP(1+P)$, a moment estimator of k is $(m'_1)^2/(m_2 - m'_1)$. From previous studies it is known that the series development for the moments of the moment estimator k^* appear to be markedly divergent (probably due to the singularity in the denominator). The present study shows that the moments of $1/k^*$ are more stable than those of k^* . Thus, if we wish to make inference about k by using 4-moment distribution fitting, then the moments of $1/k^*$ should be used, rather than those of k^* .

Research sponsored by U.S. Department of Energy.

*Bell Communications Research, Red Bank, NJ.

†University of Georgia, Atlanta, GA.

1.104

A PROBLEM WITH TRANSFORMATIONS OF STIELTJES CONTINUED FRACTIONS

L. R. Shenton* K. O. Bowman

[Abstract of *J. Comp. Appl. Math.* (in p. 28)]

A modification of a basic periodic continued fraction is studied in which the associated weight function (in the Stieltjes transform form) is multiplied by a positive factorable polynomial; this relates to the continued fraction form for certain difference operations acting on the associated power series development. A procedure is given to cope with the development of the modified continued fraction; in a number of cases the partial numerators of this continued fraction turn out to have a certain periodicity of form and are rational fractions with polynomial components. In the limit they are periodic, the period (very likely) being that of the original continued fraction.

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

*University of Georgia, Athens, GA.

Research in General Statistical Methods

1.105

GENERATION OF AN ORDERED SIMPLE RANDOM SAMPLE WITHOUT REPLACEMENT USING ONE RANDOM NUMBER

Y. H. Etheridge T. Wright

(Abstract of ORNL/TM-10868, August 1988)

Nigam and Gupta presented by examples a method for the identification of the n units to be included in a simple random sample (SRS) for selection from a finite universe of $N(> n)$ distinct and identifiable units. The method calls for the generation of only one random number to select a SRS of n units without having to list all $\binom{N}{n}$ possible samples — practically all other methods require the generation of between n and N random numbers. Wright has given a slightly faster and generalized algorithm and demonstrated that the generalized algorithm to generate a SRS has a natural relation with Pascal's Triangle. The slight improvement in speed is a direct result of the establishment of a link with Pascal's Triangle. A program that executes the generalized algorithm is described.

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

1.106

MAXIMUM LIKELIHOOD ESTIMATION FOR CYTOGENETIC DOSE-RESPONSE CURVES

E. L. Frome R. J. DuFrain*

[Abstract of *Biometrics* 42, 73 (1986)]

In vitro dose-response curves are used to describe the relation between chromosome aberrations and radiation dose for human lymphocytes. The lymphocytes are exposed to low-LET radiation, and the resulting dicentric chromosome aberrations follow the Poisson distribution. The expected yield depends on both the magnitude and the temporal distribution of the dose. A general dose-response model that describes this relation has been presented using the theory of dual ra-

diation action. Two special cases of practical interest are split-dose and continuous exposure experiments, and the resulting dose-time-response models are intrinsically nonlinear in the parameters. A general-purpose maximum likelihood estimation procedure is described, and estimation for the nonlinear models is illustrated with numerical examples from both experimental designs. Poisson regression analysis is used for estimation, hypothesis testing, and regression diagnostics. Results are discussed in the context of exposure assessment procedures for both acute and chronic human radiation exposure.

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

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.107

SURVEY DATA QUALITY CONTROL CONFERENCE: A REPORT

G. R. Liepins* V. R. R. Uppuluri

(Abstract of oral presentation presented at the 1988 Joint Meeting of the ASA Chapters of Tennessee, Hospital Corporation of America, Nashville, TN, April 23, 1988)

This talk was a brief summary of the Conference on Survey Data Quality Control held in Oak Ridge during April 21-22, 1988. Some highlights of the technical presentations of the enclosed program were reported.

Research sponsored by U.S. Department of Energy.

*Energy Division.

1.108

DETECTION OF ASSOCIATIONS BETWEEN DISEASES IN ANIMAL CARCINOGENICITY EXPERIMENTS

T. J. Mitchell B. W. Turnbull*

[Abstract of *Biometrics* (in press)]

We present a statistical test for the hypothesis of independence of two disease processes in animal carcinogenicity experiments. It is assumed that

the diseases are occult (detectable only at death via necropsy), and progressive, in that each passes (potentially) from absent to nonlethally present to lethally present in each animal. The test is based on a series of age-stratified 3×3 tables in which the animals that die in each age interval are cross-classified into one of these three states for each disease. Under the appropriate conditioning to remove the effect of nuisance parameters, we derive the null distribution of the data table in each interval, and in particular the distribution of the test statistic, which is the frequency of animals that die with neither disease. (Under the conditioning in each interval, this is equivalent to the ratio of the odds for presence of one disease to the odds for presence of the other.) The test statistics from all intervals are then combined as in a Mantel-Haenszel test to yield an overall test statistic, the total number of animals that die with neither disease, which is approximately normally distributed. This test utilizes all the data, whether obtained by sacrifice or by "natural death." It avoids the biases due to lethality noted by Breslow *et al.* for the test based on age-stratified 2×2 tables, where the nonlethal and lethal occurrences are pooled. In a simulation experiment, we show that such biases (which usually conceal true positive associations and produce spurious negative associations) can be very severe indeed, whereas our test preserves the nominal significance level quite well. The power of the test appears to vary widely, depending on the incidence, time to onset, and rate of progression of each disease. In many cases, it will be necessary to combine data from several experiments in order to detect associations.

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

*Cornell University, Ithaca, NY.

1.109

BAYESIAN VARIABLE SELECTION IN LINEAR REGRESSION

T. J. Mitchell J. J. Beauchamp

(Abstract of oral presentation presented at the University of Tennessee, Department of Statistics, Knoxville, TN, October 18, 1988)

This talk will review joint work of T. J. Mitchell and the speaker concerned with the selection of predictor variables in a linear regres-

sion model for the prediction of a dependent variable using a Bayesian approach. After specifying the necessary prior distributions and deriving the appropriate posterior model probabilities, methods are proposed for assessing the complexity of the response function. Examples based on a data set arising from an energy conservation study are given to demonstrate the application of the methods.

Research sponsored by U.S. Department of Energy.

1.110

BAYESIAN VARIABLE SELECTION IN LINEAR REGRESSION

T. J. Mitchell J. J. Beauchamp

(Abstract of oral presentation presented at the 1988 Joint Statistical Meetings, New Orleans, LA, August 22-25, 1988)

This paper is concerned with the selection of subsets of predictor variables in a linear regression model for the prediction of a dependent variable. It is based on a Bayesian approach, intended to be as objective as possible. A probability distribution is first assigned to the dependent variable through the specification of a family of prior distributions for the unknown parameters in the regression model. The method is not fully Bayesian, however, because the ultimate choice of prior distribution from this family is affected by the data. It is assumed that the predictors represent distinct observables; the corresponding regression coefficients are assigned independent prior distributions. For each regression coefficient that is subject to deletion from the model, the prior distribution is a mixture of a point mass at 0 and a diffuse uniform distribution elsewhere, i.e., a "spike and slab" distribution. The random error component is assigned a normal distribution with mean 0 and standard deviation σ , where $\log(\sigma)$ has a locally uniform "noninformative" prior distribution. The appropriate posterior probabilities are derived for each submodel. If the regression coefficients have identical priors, the posterior distribution depends only on the data and the parameter γ , which is the height of the spike divided by the height of the slab for the common prior distribution. This parameter is not assigned a probability distribution; instead, it is considered here as a parameter that indexes the members of a class of Bayesian methods. Graphical methods are proposed as informal

guides for choosing γ , for assessing the complexity of the response function and the strength of the individual predictor variables, and for assessing the degree of uncertainty about the best sub-model. The dependence of the results on the scaling of the variables is discussed, and some ways to choose the scaling constants are suggested. Examples based on a large data set arising from an energy conservation study are given to demonstrate the application of the methods.

Research sponsored by U.S. Department of Energy.

1.111

SMALL-SAMPLE CONFIDENCE LIMITS FOR PARAMETERS UNDER INEQUALITY CONSTRAINTS WITH APPLICATION TO QUANTAL BIOASSAY

M. D. Morris

[Abstract of *Biometrics* 44, 1083-1092 (1988)]

A family of methods is presented for constructing confidence limits for the parameters of a collection of distributions when a simple ordering is assumed among the parameters. The methods are shown to yield confidence limits that are exact or conservative for finite samples. For discrete distributions, one of the methods produces confidence limits that are at least as tight as the limits produced by a commonly used single-sample procedure. Confidence limits are demonstrated for a binomial quantal bioassay problem assuming a nondecreasing dose-response function. Results of a simulation study show that competing asymptotic methods can produce serious discrepancies between nominal and actual coverage probabilities for binomial samples of sizes up to 30 and demonstrate that the new approach can be competitive with the asymptotic methods when the latter maintain their nominal error rates.

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

1.112

SPARSE MATRIX COMPUTATIONS IN ANALYSIS OF VARIANCE

G. Ostrouchov

(Abstract of oral presentation presented at Kansas State University, Manhattan, KS, April 7, 1988; at the University of Tennessee, Department of Statistics, Knoxville, TN, February 25, 1988; at SIAM Conference on Applied Linear Algebra, Madison, WI, May 23-26, 1988; and at the University of Tennessee as a lecture entitled, "Sparse Least Squares Computations in Statistical Applications," Knoxville, TN, May 2-6, 1988)

Unbalanced data in analysis of variance require the explicit solution of a least squares problem. The least squares problem is sparse and can be very large, thus its solution can benefit from the use of sparse matrix techniques. The use of standard sparse matrix techniques in combination with symbolic processing that takes advantage of the special matrix structure can produce a very efficient direct method. This talk will briefly describe the analysis of variance problem and standard sparse matrix techniques for the direct solution of least squares problems. Most of the talk will concentrate on the application of sparse matrix techniques to the analysis of variance problem and symbolic processing based on model term index sets.

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

1.113

STATISTICAL COMPUTING ON A HYPERCUBE

G. Ostrouchov

(Abstract of oral presentation presented at Kansas State University, Manhattan, KS, April 5, 1988 and at the 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21-23, 1988)

A hypercube parallel computer is a network 2^n 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. Some recent experiences and results in developing a hypercube algorithm for iterative proportional fitting of large Poisson regression problems will be discussed. The algorithm is implemented on a 64-processor INTEL iPSC hypercube.

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

1.114

ANOVA MODEL FITTING VIA SPARSE MATRIX COMPUTATIONS: A FAST DIRECT METHOD

G. Ostrouchov

[Abstract of *SIAM J. Sci. Stat. Comput.* 10, 58 (1989)]

A fast and storage-efficient direct method for fitting analysis-of-variance models to unbalanced data is presented. This method exploits sparsity and rank deficiency of the model matrix and is based on orthogonal Givens factorization of a set of sparse columns of the model matrix. A class of matrices generated by index sets is defined and used to obtain results on linear dependencies between columns of a model matrix and fill during factorization. These results are used to develop an algorithm for the selection, ordering, and symbolic factorization of a set of sparse columns of the model matrix. This facilitates a fast and storage-efficient numerical factorization and solution. A comparison to both a standard direct algorithm and a general-purpose sparse least-squares algorithm shows that the new algorithm reduces time and storage by orders of magnitude for large models and is competitive for small models.

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

1.115

A MODEL SEARCH PROCEDURE FOR HIERARCHICAL LOG- LINEAR MODELS

G. Ostrouchov E. L. Frome

(Abstract of paper presented at the 1989 Joint Statistical Meetings, Washington, DC, August 6-10, 1989)

Large data sets cross-classified according to multiple factors are available in epidemiology and other disciplines. Their analysis often call for finding a set of best hierarchical log-linear models to serve as a basis for further analysis. This selection can be based on an Akaike information type statistic. Fitting all possible models to find a best set is usually not feasible for as few as five factors (7580 possible models). By noting that the set of hierarchical models and their relationships can be represented by a graph, a graph traversal algorithm is developed that requires fitting a frac-

tion of all models to find an exact subset of the best models. The algorithm classifies (in the best set/not in the best set) as many models as possible on the basis of each fit. A data structure implementing the graph keeps track of the information required by the algorithm.

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

1.116

SHRINKING TECHNIQUES FOR ROBUST REGRESSION

R. L. Schmoyer S. F. Arnold*

[Abstract of book chapter in *Contributions to Probability and Statistics, Essays in Honor of Ingram Olkin*, pp. 368-384, L. J. Gleser, M. D. Perlman, S. S. Press, and A. R. Sampson, Eds., Springer-Verlag, New York (1989)]

The asymptotic normality of robust estimators suggests that shrinking techniques previously considered for least squares regression are appropriate in robust regression as well. Moreover, the noisy nature of the data frequently encountered in robust regression problems makes the use of shrinking estimators particularly advantageous. Asymptotic and finite sample results and a short simulation demonstrate that shrinking techniques can indeed improve a robust estimator's performance.

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

*Pennsylvania State University, University Park, PA.

1.117

NEAR WITH REPLACEMENT SAMPLING WITHOUT REPLACEMENT USING RANKS

T. Wright

(Abstract of oral presentation presented at the Washington Statistical Society Meeting, Washington, DC, April 13, 1988; at Ohio State University, Statistics Department, Columbus, OH, May 17, 1988; and at the University of Tennessee, Statistics Department, Knoxville, TN, January 31, 1989)

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 a 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. The proposed sampling plan is similar to, has the simplicity of, and has no greater sampling variance than with replacement sampling, but is without replacement. The method is compared numerically with several other methods for various populations.

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

1.118

ON SOME PROPERTIES OF VARIABLE SIZE SIMPLE RANDOM SAMPLING AND A LIMIT THEOREM

T. Wright

[Abstract of *Commun. Statist.-Theory Meth.* 17(9), 2997 (1988)]

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.

1.119

A NOTE ON PASCAL'S TRIANGLE AND SIMPLE RANDOM SAMPLING

T. Wright

[Abstract of *College Mathematics Journal* 20(1), 59-66 (1989)]

Much of the theory behind the statistical analysis of sample surveys and experiments requires that the sample be selected by random sampling. Simple random sampling without replacement is the process of selecting a set of n different units from a universe of N distinct and identifiable units where each possible set of n units is equally likely to be chosen; that is, has probability $1/\binom{N}{n}$ of selection. Although the definition calls for the selection of a set of n units, in practice one usually selects a simple random sample (SRS) using a unit by unit selection scheme. Unit by unit selection schemes are favored because they do not require a complete listing of all possible samples. The selection of a SRS can be challenging, particularly when n (and N) are large and one has a sequential listing of the population units in a data file. As Bebbington notes, "the standard method would be to pick n integers at random between 1 and N , sort them, devise a method for replacing duplicates, then work through the file selecting the appropriate elements. But the method is unnecessarily costly in terms of both storage and time, particularly if n is large or the operation is to be done many times, for example in a simulation study." Typically, these methods call for the generation of at least n random numbers to obtain one SRS.

In 1984 Nigam and Gupta demonstrated by example how to select a SRS of size n without having to list all possible samples and by generating only one random number. Their method requires that one think of an ordered listing of all $\binom{N}{n}$ possible samples, generate a random integer x between 1 and $\binom{N}{n}$, and select the sample at the x th position in the list. This article contains an improvement of their method and an interesting justification based on Pascal's triangle.

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

1.120

ON A NEW TEST OF EQUALITY OF TWO PROPORTIONS BASED ON DIRECTED DIVERGENCE

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

[Abstract of Stat. Prob. Letts. (in press)]

A new procedure for testing equality of two proportions in terms of an information-theoretic

measure is presented. This measure is usually referred to as the Gini-Simpson index of diversity. In particular, use is made of the properties of the quadratic analogue of the Kullback-Liebler measure of directed divergence.

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

*Kent State University, Kent, OH.

Applications of Statistical Methods

1.121

EQUAL OPPORTUNITIES IN SCIENCE AND ENGINEERING

K. O. Bowman

(Abstract of oral presentation presented at the 1988 WATtec Conference, Knoxville, TN, February 16-19, 1988)

The United States Congress enacted (Public Law 96-516) the Science and Technology Equal Opportunities Act of 1980 to promote science and engineering for under-represented groups in the population. The Law requires the National Science Foundation to prepare the report "Women and Minorities in Science and Engineering" biennially. The fourth report was due in January 1988. For the past seven years, situations of women and minorities have improved significantly, but problems still exist. By the joint effort of the National Science Foundation and the National Research Council, a series of workshops were conducted in 1986 to understand and analyze the under-representation and carrier differentials of women and minorities in science and engineering. In this talk, we summarize the latest findings.

Research sponsored by U.S. Department of Energy.

1.122

EVALUATION OF SPECIAL NUCLEAR MATERIAL MONITORING INSTRUMENTS

K. O. Bowman S. A. Wallace*

[Abstract of International Nuclear Material Management (in press)]

A statistical method to protect against the loss of strategic special nuclear material (SSNM)

is presented. A simplified step by step approach to the test procedure is described.

Research sponsored by U.S. DOE and the Y-12 Development Department.

*Y-12 Development Division.

1.123

STATISTICAL QUALITY CONTROL TECHNOLOGY IN JAPAN

K. O. Bowman T. Hopp*
R. Kacker* R. Lundegard*

[Abstract of Scientific Information Bulletin 15(1) (1990)]

From May 17 to June 1, 1989, a survey team organized by the National Institute of Standards and Technology, visited Japan to assess research and application of statistical quality control technology. The team explored the philosophy and conduct of total quality control (TQC) in Japanese industries, government laboratories, and national agencies. The philosophy and practice of TQC in Japan is quite different from that of the U.S. industries. Our findings are similar to the findings from "R&M 2000 Variability Reduction Process Trip to Japan," B. A. Johnson.

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

*National Institute of Standards and Technology, Gaithersburg, MD.

1.124

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

A. V. Carpenter* W. D. Flanders†
E. L. Frome W. G. Tankersley*
S. A. Fry*

[Abstract of *The American Journal of Industrial Medicine* 13, 351-362 (1988)]

In a nested case-control study of workers employed between 1943 and 1977 at two nuclear facilities, we evaluated the possible association of primary CNS cancers with occupational exposure to chemicals. Seventy-two white male and 17 white female workers who, according to the information on death certificates, died of primary CNS cancers were identified as cases. For each case, four controls were matched on race, sex, facility at which initially employed (cohort), year of birth, and year of hire. Each job title/department combination was subjectively evaluated for potential exposure to each of 26 chemicals or chemical groups. Although statistically significant associations were not found between CNS cancer deaths and any of the 26 chemicals, modest effects could not be ruled out for some of these chemicals such as beryllium, cutting oils, and solvents.

Research sponsored by U.S. Department of Energy.

*Oak Ridge Associated Universities, Oak Ridge, TN.

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1.125

CHARACTERIZING OCCUPATIONAL DOSE DISTRIBUTIONS USING THE HYBRID LOGNORMAL DISTRIBUTION

B. W. Dolan* P. G. Gröer*
V. R. R. Uppuluri

(Abstract of paper presented at the Health Physics Society Annual Meeting, Albuquerque, NM, June 25-28, 1989)

Distributions of occupational radiation exposures and doses are often thought to be lognormal. The hybrid lognormal distribution was proposed by Kumazawa and Numakunai to better model the effects of exposure limits and administrative

controls on the stochastic mechanism that generates occupational exposures/doses. Using the graphical procedure detailed by Kumazawa, we estimated the parameters to fit the hybrid lognormal distribution to some dose/exposure data for workers at two nuclear facilities. One data set was well represented by the lognormal distribution, the other seemed better characterized by the hybrid lognormal distribution. The lognormal behavior of the first data set may be explained by a relatively lower level of exposures, which results in a lessening of influence of regulatory limits on the stochastic exposures.

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

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.126

STATISTICAL GRAPHICS—THE VISUAL DISPLAY

D. J. Downing

(Abstract of oral presentation presented at the Society of Manufacturing Engineers Monthly Meeting at STIK Campus, Knoxville, TN, March 3, 1988)

Graphics in the form of charts, maps, and tables presenting statistical information began around 1700. This talk will present a history of graphics dealing with graphical excellence and focus on problems that detract from graphical excellence such as: graphical deception, design variation, data variation, proportions and scaling, chart junk, data ink maximization, and others.

Research sponsored by U.S. Department of Energy.

1.127

SOME OUTLIER DETECTION METHODS IN TIME SERIES ANALYSIS

D. J. Downing

(Abstract of oral presentation presented at the University of Tennessee, Department of Statistics, Knoxville, TN, February 4, 1988)

The subject of outlier detection has been dealt with by many people. The subject has grown to the point where it could really be treated as a field in its own right. The topic of outliers in time series has been a late bloomer and is now be-

ginning to take shape—especially with the advent of the computer. This talk deals with the techniques currently used to detect outliers in time series analysis.

Research sponsored by U.S. Department of Energy.

1.128

EVALUATING GOODNESS OF FIT OF POISSON REGRESSION MODELS IN COHORT STUDIES

E. L. Frome M. D. Morris

[Abstract of *Am. Stat.* 43(3), 144-147 (1989)]

Relative and absolute risk models are often used in epidemiologic studies to describe the effect of exposure on age-specific mortality rates. Poisson regression analysis is used to obtain maximum likelihood estimates of unknown parameters and to assess goodness of fit of the model. It is common practice to base both estimation and the evaluation of goodness of fit on certain marginal totals. This approach is potentially misleading for relative risk models and is totally inappropriate for absolute risk models. To illustrate the situation, we present an example using data on smoking and lung cancer. In the example, the goodness-of-fit tests based on the marginal totals indicate that neither the absolute risk nor the relative risk model can be rejected, whereas the age-specific test statistics strongly reject both models. The validity of the marginal test is based on an assumption (i.e., of no exposure by age interaction) that is not satisfied in the example. We describe a more general approach to model evaluation that provides the analyst with summary information for various models of interest and provides guidance on how to identify good descriptive models.

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

1.129

IS p A PRIME NUMBER? SOME PROBABILISTIC TESTS OF PRIMALITY

S. R. Jammalamadaka*
V. R. R. Uppuluri

[Abstract of *Math. Scientist* 14, 55 (1989)]

A brief discussion of two probabilistic tests of primality is given. One of the main reasons for the new interest in large prime numbers comes from the so-called public-key cryptosystems. Chief among these is the RSA algorithm, which is also briefly outlined. The purpose of this note is to bring these ideas to a wider mathematical audience.

Research sponsored by U.S. DOE and the University of California, Santa Barbara.

*University of California, Santa Barbara, CA.

1.130

THE MIXED FUNCTION OXIDASE SYSTEM OF BLUEGILL SUNFISH, LEPOMIS MACROCHIRUS: CORRELATION OF ACTIVITIES IN EXPERIMENTAL AND WILD FISH

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N. E. Lee‡ J. J. Beauchamp
J. F. McCarthy§

[Abstract of *Environmental Toxicology and Chemistry* 7, 623-634 (1988)]

Environmental conditions can affect the metabolic transformation and accumulation of pollutants in aquatic organisms. Changes in temperature and feeding regimes had marked effects on the hepatic *O*-deethylation of 7-ethoxyresorufin (EROD) activity in bluegill sunfish. Animals that were denied food and acclimated for 2 weeks to 4, 13 or 26°C water exhibited low and relatively uniform EROD activity at all temperatures. In contrast, fed fish acclimated at 26°C exhibited a sevenfold higher level of activity compared with those acclimated to 4°C. Starved fish acclimated to 26°C were capable of EROD induction following intraperitoneal (i.p.) injection with benzo[a]pyrene (BaP). Doses of 10 and 20 mg BaP kg⁻¹ body weight increased EROD ac-

tivity to 100 and 300 nmol min⁻¹ mg⁻¹ respectively, compared with 10 nmol min⁻¹ mg⁻¹ in fish injected with corn oil. Wild fish obtained from various stations along a polluted stream exhibited EROD activity levels comparable with those in laboratory fish injected with 20 mg BaP kg⁻¹ fish. When starved fish were injected i.p. with a Purina Trout Chow extract, EROD activity was induced to levels comparable with those in laboratory-fed (Trout Chow) fish: this suggests the presence of an inducer in the Trout Chow. Exposure of fed fish to pH 5, 7, and 9 for a 2-week period at 26°C had no effect on the mixed function oxidase (MFO) activity in fish liver microsomes. The results of this study indicate that environmental variables can affect the levels of MFO activity. A better understanding of these effects is needed before these indicators can be used routinely as environmental monitors.

Research sponsored by U.S. Department of Energy.

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1.131

EIGHT BILLION MICE IS THE ANSWER. WHAT IS THE QUESTION? COMMENTARY FOR THE CITATION CLASSICS

M. A. Kastenbaum* K. O. Bowman

[Abstract of *Current Contents: Engineering, Technology, and Applied Science* 20(42), 18 (1989); *Current Contents: Physical, Chemical, and Earth Sciences* 20(42), 18 (1989); and *Current Contents: Agriculture, Biology, and Environmental Science* 20(42), 18 (1989)]

The previously published paper entitled "Tables for Determining the Significance of Mutation Frequencies," *Mutation Research* 9, 527-549, 1970, by Marvin A. Kastenbaum and K. O. Bowman was selected as Citation Classics. This paper provides answers to the question for the geneticist who has counted a total of n mutations in two experimental groups, "What is the number of mutation, c , in group 1 that will allow me to conclude that the mutation frequency in group 1 is significantly greater than that of group 2?"

This note is a brief commentary on this work which provides the insights of publishing this paper.

Research sponsored by U.S. Department of Energy.

*Basye, VA.

1.132

MASS LOSS AND NUTRIENT CHANGES IN DECOMPOSING UPLAND OAK AND MESIC MIXED-HARDWOOD LEAF LITTER

J. M. Kelly* J. J. Beauchamp

[Abstract of *Soil Sci. Soc. Am. J.* 51, 1616-1622 (1987)]

Nylon net litterbags (30 by 30 cm) containing ~10 g of upland oak leaf litter were collected at 30-d intervals over a 1110-d period from two upland oak (*Quercus* sp.)-mixed hardwood stands on the Cumberland Plateau of Tennessee. Statistically significant differences ($P \leq 0.01$) in losses of mass, N, K, Ca, and S were found between sites, whereas P and Mg losses did not differ. Litterbags containing mesic mixed-hardwood leaf litter were collected at 30-d intervals over a 810-d period from mesic mixed-hardwood stands located on the same watershed study sites as the upland oak stands. Statistical comparisons indicated significant differences in mass, N, P, K, Ca, Mg and S loss between sites. Constant rate projections of the time required for the upland oak litter weight to reach 10% of the original bag content based on 365, 730, and 1095 d of data were 960, 1530, and 1770 d, respectively, at the Camp Branch Watershed and 870, 1230, and 1410 d at the Cross Creek Watershed. Estimates of decomposition times derived from constant rate projections for both cover types were considerably less than observed values. In an attempt to obtain more realistic projections of weight and nutrient loss, several mathematical models commonly used to examine decomposition data were evaluated. A modified exponential model gave the best data fit and provided estimates of 3240 and 2370 d as the time required to reach the 10% mass-remaining value for the upland oak litterbags at Camp Branch and Cross Creek, respectively. Estimates for the mesic mixed-hardwoods were 1590 and 2490 d at Camp Branch and Cross Creek, respectively. The weight

of most nutrients in the litterbags was modeled with limited success by the modified exponential model. However, N and particularly P weights could not be described by the model since they generally increased with time over the study period. The results of this analysis, in addition to suggesting that a longer time is required for decomposition than is normally projected, also suggest that a single model may not be appropriate to describe all response variables. Data presented here along with the modeling work also reiterate the fact that a decay rate derived from a single species or group of species must be applied with caution over larger landscape units because of the potential differences both within and among sites.

Research sponsored by the Federal Interagency Energy/Environment Research and Development Program and the Environmental Protection Agency.

*Cooperative Forest Studies Program, Tennessee Valley Authority.

1.133

COMPARISONS OF DOSE-RESPONSE PARAMETERS FOR RADIATION-INDUCED ACENTRIC FRAGMENTS AND MICRONUCLEI OBSERVED IN CYTOKINESIS-ARRESTED LYMPHOCYTES

L. G. Littlefield* A. M. Sayer*
E. L. Frome

[Abstract of *Metagenesis* 4(4), 265-270 (1989)]

We employed cytochalasin B to block cytokinesis in human lymphocytes exposed to 220 kV X-radiation. When 3 $\mu\text{g}/\text{ml}$ of cytochalasin B was used, most cells escaped the block whereas at 6 $\mu\text{g}/\text{ml}$ >90% of the mitogen-responsive cells became binucleate. Using the higher concentration of cytochalasin B, we observed a linear-quadratic (i.e. $Y = \gamma + \alpha D + \beta D^2$) dose dependency for X-ray-induced micronuclei (MN) in preparations from three donors. When dose-response parameters were compared with those for total acentrics scored in first division metaphases, we observed no significant differences in estimates of the background (γ) or linear (α) coefficients, but a 2-fold reduction in the β coefficient for MN. We interpret our data as providing evidence that radiation-induced micronuclei are derived from acentric fragments (AF); that virtually all AF are recovered as MN in binucleate interphase daughter cells at low radiation doses; and that for our

data, the relative proportion of AF that will be observed as independent MN decreases by a constant factor of approximately one-half as radiation dose increases.

Research sponsored by U.S. Department of Energy.

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.134

MODULATION OF RADIATION-INDUCED CHROMOSOME ABERRATIONS BY DMSO-AN OH RADICAL SCAVENGER. 1. DOSE RESPONSE STUDIES IN HUMAN LYMPHOCYTES EXPOSED TO 220 kV X-Rays

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S. P. Colyer* A. M. Sayer*
E. L. Frome

[Abstract of *Int. J. Radiat. Biol.* 53(6), 875-890 (1988)]

Human G_0 lymphocytes were exposed to 220 kV X-radiation in the presence or absence of DMSO, an efficient selective scavenger of OH radicals. Our studies demonstrate that DMSO affects a concentration-dependent modulation of induced asymmetrical aberrations in human lymphocytes exposed to ~ 3.0 Gy, with maximum protectable fractions of approximately 70% at DMSO concentrations of $\geq 1\text{M}$. The dose dependency for dicentric in lymphocytes acutely exposed to X-ray doses of 0.51 to 4.98 Gy in the absence of DMSO is adequately described by the linear-quadratic dose-response function $Y = \alpha D + \beta D^2$. Data from duplicate cultures exposed in the presence of 1M DMSO produce an excellent fit to the regression function modified as follows:

$$Y(\text{DMSO}) = \alpha (\Delta D) + \beta (\Delta D)^2$$

where the 'dose modifying' factor $\Delta = 0.501$. We interpret these findings as providing evidence that OH radical-mediated lesions in DNA account for $\sim 50\%$ of the dose dependency for dicentric resulting from either one-track or two-track events, following exposures of non-cycling cells to moderate-to-high doses of low-LET radiation. These data may be used in additional calculations to derive an estimate of $\sim 6 \times 10^8 \text{ s}^{-1}$ for the rate of reaction of OH radicals with DNA targets involved in aberration formation.

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

*Oak Ridge Associated Universities, Oak Ridge, TN.

1.135

DETERMINING REGIONAL WATER QUALITY PATTERNS AND THEIR ECOLOGICAL RELATIONSHIPS

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J. J. Beauchamp

[Abstract of *Environmental Management* 11(4), 507-518 (1987)]

A multivariate statistical method for analyzing spatial patterns of water quality in Georgia and Kansas was tested using data in the US Environmental Protection Agency's STORET data system. Water quality data for Georgia and Kansas were organized by watersheds. We evaluated three questions: (a) can distinctive regional water quality patterns be detected and predicted using only a few water quality variables, (b) are regional water quality patterns correlated with terrestrial biotic regions, and (c) are regional water quality patterns correlated with fish distributions? Using existing data, this method can distinguish regions with water quality very different from the average conditions (as in Georgia), but it does not discriminate well between regions that do not have diverse water quality conditions (as in Kansas). Data that are spatially and temporally adequate for representing large regions and for multivariate statistical analysis are available for only a few common water quality parameters. Regional climate, lithology, and biotic regimes all have the potential to affect water quality, and terrestrial biotic regions and fish distribution do compare with regional water quality patterns, especially in a state like Georgia, where watershed characteristics are diverse. Thus, identifiable relationships between watershed characteristics and water quality should allow the development of an integrated land-aquatic classification system that would be a valuable tool for resource management. Because geographical distributions of species may be limited by zoogeographic and environmental factors, the recognition of patterns in fish distributions that correlate with regional water quality patterns could influence management strategies and aid regional assessments.

Research sponsored by U.S. Department of Energy.

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1.136

THE ROLE OF ASSUMPTIONS IN STATISTICAL MODELING

M. D. Morris

(Abstract of oral presentation presented at the Health Physics Society Annual Meeting, Albuquerque, NM, June 25-28, 1989)

The process of modeling biological responses to radiation, like that of any scientific modeling activity, requires both specific evidence in the form of data and general structure in the form of assumptions. These assumptions typically represent approximate or simplified statements about reality. To a great extent, their accuracy influences the validity of the modeling exercise, while their specificity influences the precision of modeling. Particularly when data are sparse, or exist in contexts somewhat removed from those for which a model is needed, selection of assumptions upon which statistical modeling is based should be considered a crucial part of the scientific process. Two examples are discussed demonstrating the effect of careful and relevant (as opposed to "automatic") assumption selection.

Research sponsored by Defense Nuclear Agency.

1.137

SOME EFFECTS OF RADIATION DOSIMETRY ERRORS ON AN ESTIMATED DOSE-RESPONSE RELATIONSHIP

M. D. Morris T. D. Jones*

[Abstract of *Health Phys.* 56(2), 219-222 (1989)]

Estimates of mortality due to marrow injury for humans exposed to ionizing radiations are commonly based upon data taken either on radiation workers following an accident or victims of Hiroshima and Nagasaki. Although these exposures are quite different, a primary source of uncertainty in the analysis of either case is the dosimetry. Various physical measurements from mockup assemblies and dose calculations are employed in order to estimate a bone marrow dose received by each individual of interest. These values are paired with the eventual result of the exposure for each individual (in this case, death or survival) in order

to estimate a dose-response function. This last step usually accomplished essentially as it would be in an experimental setting in which animals are intentionally exposed to varying doses of a controlled treatment; modeling techniques ranging from informal graphics to parametric statistical modeling are used to estimate parameters of interest such as the LD₅₀.

In the somewhat simpler modeling problem of linear regression, it has long been known that in certain cases, random errors in the independent variable can result in a biased estimate of the slope. More recently, E. S. Gilbert has presented results of calculations of bias in the estimated slope of a linear dose-response function for dichotomous data. These calculations were specific for the assumed distribution of true doses received by individuals and investigated the effects of certain modifications in data analysis such as the pooling of individuals by dose groups, removal of individuals with very high doses, etc. Examples of estimated bias for various case specific mortality dose-response calculations from Hiroshima and Nagasaki studies were also given.

Our aim is similar to Gilbert's in that we will address the degree of estimation bias (or "flattening") of a dose-response curve due to uncertainty in dose levels. However, we will not follow Gilbert's unconditional approach which requires that the distribution of doses among individuals be considered. We will specifically address the degree of distortion in the apparent dose-response relationship which exists independently of distribution of doses or statistical estimation method employed. Finally, our presentation is based upon a log-normal model, which allows simple, closed-form expressions of the effects of uncertainty in dose on the apparent LD₁₀ and other quantities of interest.

Research sponsored by Defense Nuclear Agency.

*Health and Safety Research Division.

1.138

HEMATOPOIETIC DEATH OF UNPROTECTED MAN FROM PHOTON IRRADIATIONS: STATISTICAL MODELING FROM ANIMAL EXPERIMENTS

M. D. Morris T. D. Jones*

[Abstract of *Int. J. Radiat. Biol.* 55(3), 445-461 (1989)]

Most estimates of the radiation dose lethal to 50 per cent of a human population are based on historical data taken from well-known experiences reflecting inadequately known physical and biological conditions, or from medical procedures where individual patients received advantages of modern clinical care. It has been debated as to whether the experience of unprotected man would more closely reflect that of hospital patients or of the radiobiological studies with large animals. The issue at question is whether the apparent two-fold or more increased susceptibility of large animals to death from bone marrow damage (compared with the majority of estimates for man) is due more to true inter-species differences or the lack of medical support.

This study is an attempt to assess the radiosensitivity of unprotected man in terms of the composite animal experiments. Based upon an extensive data base containing 121 separate animal studies using 13 different species, an estimate of the mortality dose-response relationship due to a uniform, continuous field of photon radiation is predicted for 70 kg unprotected man. Man is assumed to have a level of radiation sensitivity similar to that of the species represented in the data base, after adjustment for body weight. The mathematical model used includes fixed terms to account for effects of body weight and dose rate, and random terms reflecting inter- and intra-species variation and experimental error. Point predictions and 95 per cent prediction intervals are given for the LD₀₅, LD₁₀, LD₂₅, LD₅₀, LD₇₅, LD₉₀, and LD₉₅, for dose rates ranging from 0.01 to 0.5 Gy/min, and treatment times ranging from about 2 min to about 24 h. At 1 cGy/min our point prediction of the LD₅₀ is 299 cGy with an associated 95 per cent prediction interval of (168 cGy, 535 cGy). The analogous values at 50 cGy/min are 183 cGy and (103 cGy, 326 cGy).

Research sponsored by Defense Nuclear Agency.

*Health and Safety Research Division.

1.139

**STATISTICAL APPROACH TO
COMBINING THE RESULTS OF
SIMILAR EXPERIMENTS WITH
APPLICATION TO THE
HEMATOLOGIC EFFECTS OF
EXTREMELY-LOW-FREQUENCY
ELECTRIC FIELD EXPOSURES**

M. D. Morris K. T. Kimball*
T. E. Aldrich† C. E. Easterly†

[Abstract of *Bioelectromagnetics* 10, 23-34 (1989)]

A large proportion of scientific effort in investigating the possible biological effects of exposure to extremely-low-frequency (ELF) fields consists of laboratory studies on experimental animals. Most experiments in which hematologic properties are measured show no statistically significant effect due to exposure. However, some studies show significant effects, which, in general, are not clearly reproducible. A difficult question must then be addressed: Are these relatively few indications of ELF effects statistical artifacts due to the increased risk of a type I error in multiple studies, or is there a real biological effect that is undetected in most studies due to the relatively small sample sizes commonly used? A statistical approach for examining the accumulated results of multiple experiments which results in a single test for treatment effect is presented. The technique requires very mild assumptions, and is valid for experiments that vary widely in specific characteristics as exposure level, duration, and laboratory. The method is applied to the results of a collection of hematologic and serum chemistry experiments, and the combined results indicate the existence of experimental effects on some end points.

Research sponsored by Assistant Secretary for Conservation and Renewable Energy, U.S. DOE Office of Energy Storage and Distribution, Electric Energy Systems Program.

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†Health and Safety Research Division.

1.140

WEIGHTED VOTING MODELS

V. R. R. Uppuluri

(Abstract of oral presentation presented at the East Tennessee Chapter of the American Statistical Association, Oak Ridge, TN, March 8, 1988)

In the conventional system of voting where "one person has one vote," each person asserts equal influence on the outcome. On the other hand there are voting situations in which some individuals or blocks of voters effectively cast more ballots than others. Such weighted voting systems are found in the Electoral College, in voting by stockholders in a corporation and other similar situations. In this presentation, we discuss two measures of voting power of the blocks of voters, one due to Shapley and Shubik and the other due to Banzhaf. These indices of voting power will be illustrated. A probabilistic framework for these indices of power will also be discussed. An example where different methods may choose different winners will be illustrated. Further, there will be a brief discussion on "approval voting."

Research sponsored by U.S. Department of Energy.

1.141

**AN APPLICATION OF THE
MAXIMUM RATIO FOR
COMPARING DIFFERENT
PETROLEUM ESTIMATES**

T. Wright

(Abstract of oral presentation presented at the 1988 Joint Statistical Meetings, New Orleans, LA, August 22-25, 1988)

Tsao and Wright (1983) introduced a simple tool called the maximum ratio that can be used when comparing several estimates $\theta_1, \theta_2, \dots, \theta_m$ (possibly from different sources) of the same parameter. The maximum ratio not only gives a measure of closeness among the comparable estimates, but also gives an indication of how the collection of estimates stands relative to the unknown true value of θ . As part of a recent Frames Update Project sponsored by the Petroleum Supply Division (PSD) of the Energy Information Administration of the U.S. Department of Energy, the maximum ratio was applied to nationwide estimates for the fuels: motor gasoline, distillate fuel, and

residual fuel. This paper illustrates the application of the maximum ratio in the project as a first step towards assessing the quality (completeness) of a sampling frame.

Research sponsored by U.S. DOE Energy Information Administration.

1.142

**WHEN ZERO DEFECTIVES APPEAR
IN A SAMPLE: UPPER
CONFIDENCE COEFFICIENTS
OF UPPER BOUNDS**

T. Wright

[Abstract of American Statistician (in press)]

When zero defectives are observed in a sample from a finite universe, investigators and decision makers are often tempted to (and want to) declare that there are zero defectives in the finite universe with high confidence. By focusing on the more general question of upper bounds for confidence coefficients of upper confidence bounds, as a special case we are able to show explicitly that our confidence that there are zero defectives in the universe when zero defectives appear in the sample is bounded by the sampling fraction. This note is meant to help reassure those who seek to help others yield not to the temptation mentioned above.

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

Section 2

NUCLEAR DATA MEASUREMENT AND EVALUATION

2.0. INTRODUCTION

R. W. Peelle

Our primary effort is devoted to experiments using the Oak Ridge Electron Linear Accelerator (ORELA) pulsed neutron source to obtain neutron cross sections needed for efficient and safe application of nuclear technology. Additional effort is expended combining experimental results with theory to generate complete sets of evaluated cross sections which are used by engineers to design and evaluate systems that require nuclear data as input. In the US, the cooperatively evaluated and tested file of such evaluations is called ENDF/B. The first release of ENDF/B version VI is expected by early 1990, about a decade after the corresponding release of ENDF/B-V. About 60% of the evaluations were performed by our group. The new file will be quite superior to previous ones in its physics content, and will surpass many of the goals set out several years ago. However, the current body of knowledge will not be completely represented by this release, so future releases of ENDF/B-VI revisions are anticipated.

We contributed strongly in three areas in which ENDF/B-VI is markedly improved:

- (a) Realistic neutron emission angular distributions as a function of neutron energy are now included to properly treat the 14-MeV neutrons produced in a fusion reactor. This was possible because of our fundamental improvements in the pre-equilibrium part of the comprehensive models used, as implemented in our TNG nuclear model code, and because of newly extended ENDF format capabilities.
- (b) New resonance-region parameterizations are included for the most important fission fuel materials and for some structural materials. These are based primarily on fits to the resonance structure of new ORELA data using SAMMY, our advanced resonance fitting system. SAMMY is based on the appropriate Reich-Moore R-matrix formalism. The collaboration with Herve Derrien, now on his third visit from CEN Cadarache, France, on ^{239}Pu and ^{241}Pu has been particularly noteworthy.
- (c) Finally, more general formats have been developed to remove some severe constraints on our variance/covariance evaluations. In the first two cases the best fruits of our effort will appear in the first release of the file. Covariance data will be incomplete in this first release because of time pressure.

This year has been an exciting time at ORELA. Because of our expertise in neutron detection, staff members became involved in some "cold fusion" confirmation efforts. We didn't demonstrate any neutron emission. More exciting in the long run, we are working with visitors on a most interesting array of experiments:

- (a) M. C. Moxon of AERE Harwell, England, is making measurements of η (average number of neutrons emitted from fission per neutron absorbed) for ^{235}U in the thermal neutron energy range where $\eta(E)$ can affect the performance and temperature coefficient of reactivity of commercial light-water reactors.
- (b) Al Wasson and Roald Schrack from the National Institute of Science and Technology (formerly NBS) are remeasuring with our help the $^{10}\text{B}(n, \alpha\gamma)$ reaction so important to the use of ^{10}B as a neutron standard. It has proven difficult to measure this cross section with good accuracy.
- (c) Jöurg Schmiedmiedler and Peter Riehs of the University of Vienna, Austria, are measuring the electric polarizability of the neutron with our collaboration. The technique depends on a precision measurement of the energy dependence of the total cross

section of ^{208}Pb , a nuclide with suitably high nuclear electric field and sufficiently few resonances to allow nuclear effects to be analyzed.

One reason these experimenters have sought out ORELA is that the electron linacs at NIST and at Harwell have been shut down. The other reason is that intensity and background considerations make ORELA the best choice in any case.

Users from within ORNL have also been doing unusually interesting work. Herb Mook has been checking out published results that the copper in the high temperature superconductor $\text{YBa}_2\text{Cu}_3\text{O}_7$ exhibits an unusually high Debye temperature. The measured Doppler spreading of copper neutron resonances in transmission is inconsistent with this suggestion. Lester Hulet and Dave Donahue have produced a strong parasitic positron beam from ORELA and are proving its utility for experiments on unique molecular excitations and on near-surface materials properties.

The years just ahead promise to be productive as the above experiments are completed, as we exercise an updated system for measurement and analysis of capture gamma ray cross sections in the resonance region where they have proven to be tricky to measure in medium-A nuclides, as we commission a photon multiplicity detector for low energy capture cross sections in fissile nuclides, as we carry forward a neutron emission spectrum program important to cross sections in the fusion energy region, and as we complete evaluation refinements for updates for ENDF/B-VI. Funding stringency is expected to stretch the program and delay new experiment starts not staffed by guests.

Fe-56 ORELA Total and Elastic Cross Section Data and Analysis. In the upper graph the ^{56}Fe 200-m total cross section data are compared with the theoretical calculations obtained with the multilevel R-matrix code SAMMY. The spins and parities were assigned using the elastic scattering data shown in the three lower graphs. The parameters obtained from the fit to the transmission data were used to calculate the theoretical elastic scattering cross section with the R-matrix code RFUNC. The combination of spins and parities adopted is the one which yields the best agreement with the elastic scattering data. Parentheses are used to indicate that the assignment is uncertain.

EXPERIMENTAL RESULTS

2.1

THE ^{151}Sm BRANCHING, A PROBE FOR THE IRRADIATION TIME SCALE OF THE s -PROCESS

H. Beer* R. L. Macklin

[Abstract of *Astrophys. J.* 331, 1047 (1988)]

The excitation functions for the reactions $^{152,154,155,157}\text{Gd}(n,\gamma)$ have been measured over the neutron energy range of 5 keV to 500 keV. Maxwellian averaged capture cross sections for thermal energies $kT=5$ to 100 keV have been calculated. At $kT=30$ keV we have found: $\sigma(^{152}\text{Gd}) = 1003 \pm 30$ mb, $\sigma(^{154}\text{Gd}) = 878 \pm 27$ mb, $\sigma(^{155}\text{Gd}) = 2721 \pm 90$ mb, $\sigma(^{157}\text{Gd}) = 1355 \pm 39$ mb. The data, in conjunction with other cross sections and solar abundances, were used to carry out an s -process analysis of the branchings in the Sm to Gd mass range. The s -process is treated in the classical as well as in the pulsed model. The solution of the classical model is contained in the pulsed model as the asymptotic solution for large pulse widths. It is shown that this solution is the only one which can reproduce the abundance pattern of the different branchings. Pulse durations are limited to values larger than about 3 yr.

Research sponsored by Kernforschungszentrum Karlsruhe, Institut für Kernphysik III, Karlsruhe 1, FRG and by U.S. DOE Division of Nuclear Physics.

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2.2

MEASUREMENT OF THE ^{85}Rb AND ^{87}Rb CAPTURE CROSS SECTIONS FOR s -PROCESS STUDIES

H. Beer* R. L. Macklin

[Abstract of *Astrophys. J.* 339, 962 (1989)]

The excitation functions for the reactions $^{85,87}\text{Rb}(n,\gamma)$ have been measured over the neutron energy range of 175 eV to 700 keV. Maxwellian averaged capture cross sections for thermal energies $kT=5$ -100 keV have been calculated. The data were used to carry out s -process calculations. Solar s -process abundances were reproduced with a two component phenomenological model below mass number 90, a single flux weak s -process and

a pulsed s -process characterized by exponentially distributed neutron exposures. The solar s -process abundances as well as s -process abundances from Ba stars and the Murchison meteorite were studied in the frame of the AGB-models. Constraints were derived concerning the properties of the neutron pulses for a description of the empirical s -process data.

Research sponsored by Kernforschungszentrum Karlsruhe, Institut für Kernphysik III, Karlsruhe 1, FRG and by U.S. DOE Division of Nuclear Physics.

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2.3

TESTS FOR "COLD FUSION" IN THE PD-D₂ AND TI-D₂ SYSTEMS AT 40 TO 380 MPa AND -196 TO 27°C

J. G. Blencoe* M. T. Naney*
D. J. Wesolowski* F. G. Perey

[Abstract of *Fusion Energy* (in press)]

Experiments have been conducted on the Pd-D₂ and Ti-D₂ systems at 40 to 380 MPa and -196 to 27°C to investigate the possibility that "cold fusion" occurs in palladium and titanium deuterides generated by reaction with high-pressure D₂ gas. The experiments were performed using a 4.8 mm i.d. stainless steel pressure vessel that can be operated routinely at pressures as high as 400 MPa.

Experimental results obtained so far range from negative to potentially significant. No sustained heat production has been observed in any experiment. Thermal pulses that persist briefly after pressurizing Pd with D₂ gas are attributable to small amounts of chemical heat released when Pd and D₂ react to form palladium deuteride. No sustained neutron flux above background was observed in any Pd-D₂ experiment.

On the other hand, in a Ti-D₂ experiment just completed, potentially significant results were obtained. During this experiment, there was a period of five consecutive hours when count rates rose to approximately 60 counts/hour above the average background rate. This detector count rate corresponds nominally to 1000 neutrons/hour

emitted from the Ti-D₂ sample. However, due to several deficiencies in our neutron detection methods and equipment, we cannot demonstrate conclusively that our experimental data are valid. Consequently, we are upgrading our neutron detection equipment in preparation for a second, improved Ti-D₂ experiment.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Chemistry Division.

2.4

LEVEL DENSITIES FROM RESONANCE SPECTROSCOPY FOR $n + {}^{86}\text{Kr}$

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C. H. Johnson‡ N. W. Hill§
J. A. Harvey

[Abstract of oral presentation given at the American Physical Society Annual Spring Meeting, Baltimore, MD, April 18-21, 1988; Proc. Vol. 33(4), p. 1061 (1988)]

High resolution transmission measurements on a high purity ${}^{86}\text{Kr}$ gas sample were performed at the ORELA facility over the neutron energy range of 0.015-25 MeV. From R-Matrix analysis of these data in the resolved resonance region below 1 MeV, we have determined the $n + {}^{86}\text{Kr}$ level densities for $J^\pi = 1/2^+$, $1/2^-$, $3/2^-$ reaction channels in the 1-MeV energy interval above neutron binding. The energy dependence of the $3/2^-$ level density, for which the uncertainties are smallest, is suitably modeled by a back-shifted Fermi gas model with two adjustable parameters. This model is then used to predict the level densities for $j^\pi = 1/2^+$ and $1/2^-$. Except for an unusual non-statistical behavior in the 500-600 keV region for the $1/2^-$ cumulative number of levels, the model is seen to give an excellent description of all three data sets. Parameters obtained are consistent with systematic trends in this mass region.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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§Instrumentation and Controls Division.

2.5

UNIFIED DESCRIPTION OF THE $n + {}^{209}\text{Bi}$ MEAN FIELD BETWEEN 1 MeV TO 40 MeV VIA DISPERSION RELATIONS

R. K. Das* R. W. Finlay*
J. A. Harvey

[Abstract of paper presented at the American Physical Society Annual Spring Meeting, Baltimore, MD, April 18-21, 1988; Proc. Vol. 33(4), p. 964 (1988)]

The real part of the central $n + {}^{209}\text{Bi}$ mean field is the sum of a Hartree-Fock component whose radial dependence is assumed to have a Wood-Saxon shape and whose depth is energy dependent plus a dispersive component which is determined from the imaginary part of the optical model potential. Elastic neutron scattering data from 1.5 MeV to 24 MeV, along with total cross section from 1 to 40 MeV, is used for the above analysis. The energy dependence of the geometry of the optical model is also studied.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.6

USE OF MONTE CARLO TECHNIQUES TO DERIVE YIELDS FOR $n + {}^{12}\text{C}$ MULTI-BODY BREAKUP REACTIONS

J. K. Dickens

[Abstract of *Computers in Physics* 3, 62 (1989)]

A computer "experiment" using Monte Carlo sampling methods has been designed to simulate the breaking up of ${}^{12}\text{C}$ by medium-energy neutrons into final reaction channels having 2, 3, or 4 outgoing charged particles. The calculational nuclear physics concept used in the "experiment" is one of a sequentially decaying highly-excited compound nucleus. Two methods of Monte Carlo sampling, the rejection method and the cumulative-distribution method, are discussed as applied to probability functions developed in the program.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.7

$^{10,11}\text{B}(\text{n},\gamma)$ REACTIONS FOR INCIDENT NEUTRON ENERGIES BETWEEN 0.1 AND 25 MeV

J. K. Dickens D. C. Larson

[Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saikon Publishing Co., Ltd., pp. 213-215 (1988)]

Measurements have been made of gamma-ray production due to neutron interactions with samples of boron for incident neutron energies between 0.1 and 25 MeV. For ^{11}B a 54-g sample of naturally-occurring boron in the shape of a solid cylinder was used. For ^{10}B , samples enriched to 95% in the ^{10}B isotope were used. One sample, about 49 g, was used to obtain γ -ray data following inelastic scattering; the other sample, of about 15 g, was used to delineate the production of the 478-keV gamma ray following the $^{10}\text{B}(\text{n},\alpha)^7\text{Li}$ reaction for E_n between 0.1 and 4 MeV. The Oak Ridge Electron Linear Accelerator (ORELA), a white source, was used to provide the incident neutrons. Data were obtained using a high-purity intrinsic-germanium photon detector positioned at 125 deg with respect to the incident neutron beam. Because the peak shapes in the raw data were substantially broadened by Doppler motion, peak yields were determined with graphic interactive methods. Except for the 478-keV gamma ray for $E_n < 1$ MeV, the γ -ray production cross sections are all small, the largest being < 200 mb.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.8

THE NE-110 SCINTILLATOR RESPONSE TO 10- TO 100-MeV CARBON IONS

J. K. Dickens J. W. McConnell *

[Abstract of Nucl. Instrum. Methods in Physics Research A281, 577 (1989)]

Measurements of the response of NE-110 organic scintillator to 13-, 34-, 44-, 70-, and 95-MeV incident carbon ions are reported.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Physics Division.

2.9

A NE 110 SCINTILLATION DETECTOR FOR keV ENERGY NEUTRONS

J. A. Harvey N. W. Hill*

[Abstract of paper presented at the American Physical Society Annual Meeting, Baltimore, MD, April 18-21, 1988; Proc. Vol. 33(4) p. 1078 (1988)]

We have developed a neutron detector with a narrow resolution function which is efficient for keV energy neutrons, has low background, and is not sensitive to overlap neutrons (< 200 eV) so the pulsed accelerator can be operated at a high repetition rate (800 pps). The detector consists of a 9- by 9-cm NE 110 scintillator, 1 cm thick, mounted in a 0.025-mm mylar reflecting cylinder, and epoxy-coupled on opposite edges to two 12.5-cm-diameter RCA 8854 photomultipliers (PMs). Each PM is biased below the single photoelectron level, and a coincidence is required between the outputs of the two PMs to eliminate counts due to PM noise. The detector has been studied down to a neutron energy of 50 eV. The observed signal-to-background ratio was 300 at 12 keV and 30 at 2 keV. The detector has an efficiency of 40% at 15 keV (ten times that of a 1-cm-thick ^6Li glass scintillation detector) and its efficiency equals that of the ^6Li detector at 4 keV. The timing resolution of the detector is 7 nsec for 10-keV neutrons, limited by the neutron flight time through the scintillator and is less for higher energy neutrons. Results from transmission measurements on ^{238}U will be presented.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Instrumentation and Controls Division.

2.10

HIGH-RESOLUTION NEUTRON TRANSMISSION MEASUREMENTS ON ^{235}U , ^{239}Pu , AND ^{238}U

J. A. Harvey N. W. Hill*
F. G. Perey G. L. Tweed†
L. Leal†

[Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saikon Publishing Co., Ltd., pp. 115-118 (1988)]

High-resolution transmission measurements have been made on three sample thicknesses of both ^{235}U and ^{239}Pu at liquid nitrogen temperature and also on three of ^{238}U at room temperature using neutrons from the water moderated ORELA target. The data on ^{235}U and ^{239}Pu from 1 to 10,000 eV were obtained using ^6Li glass scintillation detectors at 17.909- and 80.394-m flight paths. The ^{238}U data from 1 to 100 keV were obtained using a new NE 110 proton-recoil scintillation detector at a 201.558-m flight path.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Instrumentation and Controls Division.

†University of Tennessee, Knoxville, TN.

2.11

COLD FUSION NEUTRON MEASUREMENTS AT ORNL

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C. A. Bennett* C. C. Havener*
C. H. Ma* F. G. Perey
R. R. Spencer J. K. Dickens
B. D. Rooney J. Bullock, IV†
G. L. Powell†

[Abstract of paper presented at the Workshop on Cold Fusion Phenomena, Santa Fe, NM, May 23-25, 1989; and a paper entitled "A Search for Cold Fusion Neutrons at ORELA" presented at the Spring Meeting of the American Physical Society, Baltimore, MD, May 1-4, 1989; Proc. Vol. 34(4) (1989)]

A number of experiments were begun on March 29, 1989 to look for neutron emission from a palladium cathode in an electrolytic cell using a deuterated electrolyte. Several different electrode configurations were tried. The fast neutron detector utilized a pair of NE213 scintilla-

tor/photomultiplier pairs in a shielded enclosure. This neutron detector has an efficiency of 13% and records a background count rate of 200 events per hour. At present no neutron counts above the background level have been detected.

Research sponsored by U.S. Department of Energy.

*Physics Division.

†Y-12 Development Division.

2.12

$^{53}\text{Cr}(n,n'\gamma)$ REACTIONS AND THE LEVEL STRUCTURE OF ^{53}Cr

D. C. Larson J. K. Dickens

[Abstract of *Phys. Rev. C* 39, 1736 (1989)]

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. Measured gamma-ray production cross sections have been compared with earlier measurements and with cross sections calculated using precompound-compound-nucleus theory. Although agreement with earlier work is generally adequate, some of the present results are at variance with earlier experimental or evaluated results. For example, for the decay of the $E_x = 1537$ -keV level we are unable to explain variations in the measured branching ratios of the transition gamma rays as a function of incident neutron energy. The experimental data were analyzed within the framework of several theoretical model calculations of the level structure of ^{53}Cr . Some quantitative discrepancies are discussed.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.13

NEUTRON CAPTURE BY ^{79}Br , ^{81}Br , AND ^{75}As

R. L. Macklin

[Abstract of *Nucl. Sci. Eng.* 99, 133 (1988)]

Neutron capture up to 700 keV was measured for arsenic and bromine and for an enriched sample of ^{81}Br . Individual resonance capture was parameterized in the first several kilo-electron-volts

and average capture cross sections derived at the higher energies. Maxwellian average cross sections found for $^{79,81}\text{Br}$ and ^{75}As , respectively, were 741 ± 30 , 244 ± 10 , and 455 ± 18 mb for a temperature $kT = 30$ keV. Resonance capture integrals calculated for $^{79,81}\text{Br}$, respectively, were $130 \pm$ and 46.6 ± 1.8 b.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.14

SEARCH FOR ^{136}Xe RESONANCE NEUTRON CAPTURE

R. L. Macklin

(Abstract of ORNL/TM-10766, May 1988)

Evidence for neutron capture in ^{136}Xe at 2154-eV and 18.4-keV resonances is presented and quantified in terms of limits on Breit-Wigner single level parameters. Assuming the radiation width, 32 meV, found at the 18.4-keV resonance for all the reported resonances at higher energies, the Maxwellian average capture cross section is calculated for a range of stellar interior temperatures T . For $kT=30$ keV only 0.72 mb is found. Only one-third of this comes from the resonances above 18.4 keV so an overall uncertainty at $kT=30$ keV of ± 0.11 mb at the 68% probability level seems reasonable. Four resonances in ^{134}Xe were also found.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.15

NEUTRON ABSORPTION CROSS SECTION OF URANIUM-236

R. L. Macklin C. W. Alexander*

(Abstract of *Nucl. Sci. Eng.* (in press); also ORNL/TM-10999, November 1988)

U-236 neutron absorption was measured as a function of neutron time-of-flight from 20 eV to 1 MeV. The neutron flux was monitored with a ^6Li glass scintillator. Average cross-sections from 3 keV to 1 MeV were derived. Estimated uncertainties were less than 5% below 600 eV and increased

to 9.5% at 1 MeV. From 20 eV to 4.2 keV neutron energy 293 resonance peaks were parameterized.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Chemical Technology Division

2.16

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

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

[Abstract of ORNL/TM-10666, January 1988; also paper entitled, "High Energy Resolution Measurements of the U-238 Neutron Capture Yield in the Energy Region Between 1 and 100 keV," presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saikon Publishing Co., Ltd., pp. 71-74 (1988)]

A measurement of the ^{238}U neutron capture yield was performed at the 150-m flight path of the ORELA facility on two ^{238}U samples (0.0124 and 0.0031 atoms/barn). The capture yield data were normalized by Moxon's small resonance method. The energy resolution achieved in this measurement frequently resulted in doublet and triplet splittings of what appeared to be single resonances in previous measurements. This resolution should allow extension of the resolved resonance energy region in ^{238}U from the present 4-keV limit up to 15- or 20-keV incident neutron energy. Some 200 small resonances of the ($^{238}\text{U} + n$) compound nucleus have been observed, which had not been detected in transmission measurements, in the energy range from 250 eV to 10 keV.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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†Instrumentation and Controls Division.

2.17

NEUTRON CAPTURE OF ^{122}Te , ^{123}Te , ^{124}Te , ^{125}Te , AND ^{126}Te

R. L. Macklin R. R. Winters*

(Abstract of ORNL-6561, July 1969)

Isotopically enriched samples of the tellurium isotopes from mass 122 to mass 126 were used to measure neutron capture in the energy range 2.6 keV to 600 keV at the Oak Ridge Electron Linear Accelerator pulsed neutron source. Starting at 2.6 keV, over 200 Breit-Wigner resonances for each isotope were used to describe the capture data. Least-squares adjustment gave parameters and their uncertainties for a total of 1659 resonances. Capture cross sections averaged over Maxwellian neutron distributions with temperatures ranging from $kT = 5$ keV to $kT = 100$ keV were derived for comparison with stellar nucleosynthesis calculations. For the three isotopes shielded from the astrophysical r -process, ^{122}Te , ^{123}Te and ^{124}Te at $kT = 30$ keV the respective values were (280 ± 10) mb, (819 ± 30) mb and (154 ± 6) mb. The corresponding products of cross section and solar system abundance are nearly equal in close agreement with s -process nucleosynthesis calculations.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.18

RESONANCE NEUTRON CAPTURE BY ARGON-40

R. L. Macklin R. R. Winters*
D. M. Schmidt†[Abstract of *Astron. Astrophys.* 216, 109-112 (1969)]

Neutron capture by ^{40}Ar at resonances up to 150 keV has been measured and parametrized using the single-level Breit-Wigner formula. Velocity weighted maxwellian averaged capture cross sections are presented for use in stellar nucleosynthesis calculations for stellar temperatures from $kT=5$ to 60 keV. The results are almost constant above $kT=10$ keV because most of the resonances lie at higher energies. At the conventional s -pro-

cess temperature $kT=30$ keV the maxwellian averaged capture cross section found is (2.79 ± 0.15) mb.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.19

NEUTRON SCATTERING IN ^{189}Os FOR NUCLEOSYNTHESIS RATES OF THE ODD-A Os ISOTOPES AND NUCLEOCHRONOLOGY

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R. L. Hershberger‡ Z. Cao§
R. L. Macklin N. W. Hill#[Abstract of *Phys. Rev. C* 40, 591 (1989)]

Neutron elastic and inelastic scattering cross sections have been determined for neutrons incident on ^{189}Os at three very low energies. Cross sections for scattering to the ground state and 36.2-keV excited level have been measured for incident energies of 63.5, 73.3, and 97.5 keV. Scattering to the 69.6 keV excited level has also been measured at 97.5 keV incident. These measurements are combined with neutron scattering cross sections for ^{187}Os , neutron capture cross sections, and other low energy scattering observables to provide a basis for a consistent model of all data for both odd-A Os isotopes. The properly interpreted capture rates are important for the Re/Os nucleochronology and for s -process nucleosynthesis rate estimates. The neutron capture and inelastic scattering cross sections provide a very low energy test of statistical model flux distributions, important in confirming the validity of the statistical model at these energies; model accuracy tests at very low energies is an important issue for reaction rates used in nucleosynthesis estimates.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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#Instrumentation and Controls Division.

2.20

**$^{58}\text{Ni} + n$ TRANSMISSION,
DIFFERENTIAL ELASTIC
SCATTERING AND CAPTURE
MEASUREMENTS AND ANALYSIS
FROM 5 TO 813 keV**

C. M. Perey F. G. Perey
J. A. Harvey N. W. Hill*
N. M. Larson† R. L. Macklin

(Abstract of ORNL/TM-10841, September 1988)

High-resolution neutron measurements for ^{58}Ni -enriched targets were made at the Oak Ridge Electron Linear Accelerator (ORELA) from 100 eV to ≈ 20 MeV in transmission, from 10 keV to 5 MeV in differential elastic scattering, and from 2.5 keV to 5 MeV in capture. The transmission data were analyzed from 10 to 813 keV with the multilevel R-matrix code SAMMY which uses Bayes' theorem for the fitting process. This code provides energies and neutron widths of the resonances inside the 10- to 813-keV region as well as a possible parameterization for resonances external to that region to describe the smooth cross section from 10 to 813 keV. The differential elastic data at different scattering angles were compared to theoretical calculations from 30 to 813 keV using an R-matrix code based on the Blatt-Biedenharn formalism. Various combinations of spin and parity were tried to predict cross sections for the well defined $\ell > 0$ resonances, and comparison with the data then provided spin and parity assignments for most of these resonances. The capture data were analyzed from 5 to 450 keV with a least-squares fitting code using the Breit-Wigner formula. In this energy region 30% more resonances were observed in the capture data than in the transmission data.

From 5 to 813 keV, 477 resonances are reported. The reduced widths of the 62 s -wave resonances follow the Porter-Thomas distribution and their nearest neighbor spacings agree with the Wigner distribution. The average s -wave level spacing is equal to 13.6 ± 0.5 keV and the s -wave strength function to $(3.1 \pm 0.6) \times 10^{-4}$. The staircase plot of the s -wave reduced level widths and the plot of the Lorentz-weighted strength function show only a slight possibility of doorway states. The level densities calculated with the Fermi-gas model for $\ell = 0$ and $\ell > 0$ resonances are compared with the cumulative number of observed resonances. The average radiation

widths were deduced from resonances analyzed in the three data sets below 450 keV. The mean values of the distributions of the radiation widths are equal to 2.3 eV for the s -wave resonances, 0.77 eV for the p -wave resonances, and 1.3 eV for the d -wave resonances and the standard deviations are 1.7 eV, 0.33 eV, and 0.5 eV, respectively. The correlation coefficient between the s -wave reduced neutron widths and radiation widths is equal to 0.66 ± 0.11 . The average capture cross section as a function of the neutron incident energy is compared to prediction based on the tail of the giant electric dipole resonance.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Instrumentation and Controls Division.

†Computing and Telecommunications Division.

2.21

**RESPONSES OF C_6D_6 AND
 C_6F_6 GAMMA-RAY DETECTORS
AND THE CAPTURE IN THE
1.15-keV RESONANCE OF ^{56}Fe**

F. G. Perey J. O. Johnson
T. A. Gabriel R. L. Macklin
R. R. Winters* J. H. Todd†
N. W. Hill†

(Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saikon Publishing Co., Ltd., pp. 379-382 (1988))

We have used the electron gamma-ray transport code EGS to calculate responses of C_6D_6 and C_6F_6 gamma-ray detectors, where the geometry of the capture experiments was carefully modelled. Very good agreement was obtained with spectra from selected responses in the capture of neutrons by ^{207}Pb . Weighting functions based upon the calculated responses were used in measuring the capture in the 1.15-keV resonance of ^{56}Fe relative to the capture in the Au 4.9-eV resonance. The neutron width was measured to be 64.5 ± 3 meV with C_6F_6 detectors and 63.0 ± 2.5 meV with C_6D_6 detectors. These values are in good agreement with the value of 61.7 ± 0.9 meV found from transmission measurements.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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†Instrumentation and Controls Division.

2.22

SUBTHRESHOLD AND NEAR-SUBTHRESHOLD FISSION PHYSICS MEASUREMENTS AT THE OAK RIDGE ELECTRON LINEAR ACCELERATOR FACILITY

R. B. Perez G. de Saussure
F. C. Difilippo L. W. Weston
J. A. Harvey

(Abstract of paper presented at the American Nuclear Society and National Bureau of Standards Conference on Fifty Years with Nuclear Fission, Gaithersburg, MD, April 26-28, 1989)

This paper is an account of the work performed at the Oak Ridge Electron Linear Accelerator (ORELA), pertaining to the fission phenomena taking place at energies of the fissioning nucleus which are comparable to the fission barrier potential energy. In this energy region, fission cross-section measurements yield information on the physical properties of the barrier and on the nuclear states at high nuclear deformations. The ORELA facility intense pulsed neutron source and good energy resolution capabilities afford a convenient tool to carry out a program of measurements in the subthreshold and near-subthreshold regions.

Extensive and precise measurements in the actinide region were performed at the ORELA facility by an international group of researchers. These measurements were unique in many respects: fission widths and areas were determined for many previously unreported resonances in the subthreshold region and a most detailed study was performed on the physical properties of the fission barrier at high nuclear deformations.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.23

HIGH RESOLUTION FISSION CROSS SECTION MEASUREMENTS AT ORELA

L. W. Weston J. H. Todd*

(Abstract of paper presented at the American Nuclear Society and National Bureau of Standards Conference on Fifty Years with Nuclear Fission, Gaithersburg, MD, April 26-28, 1989)

Multi-level fitting of the transmission, fission and capture cross sections have dramatically indi-

cated the need for higher resolution fission cross section measurements of the fissile nuclides. High resolution is needed for extending the resolved resonance region to higher neutron energies, investigation of theoretical phenomena and background determination.

New measurements of the neutron fission cross sections of ^{235}U and ^{239}Pu have been carried out with the white neutron source of ORELA at a flight path of 85 meters. Fission chambers with fast current amplifiers and a parallel plate ^{10}B ionization chamber were used as detectors. These measurements have resolution more nearly comparable with recent transmission measurements and will aid in multi-level fits to higher neutron energies than previously feasible.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Instrumentation and Controls Division.

2.24

NEW CROSS SECTION EVALUATIONS FOR REACTOR FUEL MATERIALS

L. W. Weston P. G. Young*
W. P. Poenitz†

[Abstract of *Trans. Am. Nucl. Soc.* 60, 606 (1989)]

There were major new evaluations for the "Big 3" (U-235, U-238, and Pu-239) and the "Little 2" (Pu-240 and Pu-241) for ENDF/B-VI. New and improved analysis methods and models were used for the thermal parameters, the resolved resonance region, the unresolved resonance region and the high-energy neutron region of smooth cross sections. The maturing of evaluation techniques and methods in the eleven years since ENDF/B-V has been most impressive. Appreciable amounts of new nuclear data have also become available.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.25

$n + {}^{40}\text{Ar}$ s- AND p-WAVE NEUTRON RESONANCE SPACINGS AND STRENGTH FUNCTIONS

R. R. Winters* R. F. Carlton†
C. H. Johnson‡

[Abstract of paper presented at the American Physical Society Meeting, Baltimore, MD, May 1-4, 1980; Proc. Vol. 34(4), p. 1243 (1989)]

Using the ORELA we have measured the neutron total cross section for $n + {}^{40}\text{Ar}$ for incident neutrons in the energy range 10 keV to 50 MeV. Below 1500 keV the energy resolution of the mea-

surement is sufficiently good to allow an R-Matrix description of the cross section with little ambiguity in the J^π assignments for the observed resonances. Our preliminary estimates for the level spacings are (63 ± 7) , (33 ± 3) , and (27 ± 2) keV for $J^\pi = 1/2^+$, $1/2^-$, and $3/2^-$, respectively. The neutron strength functions for the same partial waves are (0.77 ± 0.25) , (1.3 ± 0.3) and (0.30 ± 0.06) in 10^{-4} units.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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NEUTRON RESONANCE ANALYSES

2.26

CURRENT PLUTONIUM CROSS- SECTION EVALUATIONS IN THE RESOLVED RESONANCE REGION

H. Derrien* G. de Saussure

[Abstract of paper presented at the 1988 International Reactor Physics Conference, Jackson Hole, WY, September 18-21, 1988; Proc. Supplement, p. S-65 (1988)]

The resonance parameter analysis code SAMMY was used to perform consistent resonance analyses of several ${}^{239}\text{Pu}$ and ${}^{241}\text{Pu}$ fission and capture cross-section and transmission measurements up to 1 keV for ${}^{239}\text{Pu}$ and up to 300 eV for ${}^{241}\text{Pu}$. The method of analysis, the measurement selection, and the results are discussed in this paper.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Centre d'Etudes Nucleaires de Cadarache, France.

2.27

R-MATRIX ANALYSIS OF ${}^{239}\text{Pu}$ NEUTRON CROSS SECTIONS IN THE ENERGY RANGE UP TO 1000 eV

H. Derrien* G. de Saussure

(Abstract of ORNL/TM-10986, January 1989)

The report is a description of the analysis of the ${}^{239}\text{Pu}$ neutron cross sections in the resolved resonance region using the multilevel-multichannel Reich-Moore code SAMMY. The resonance

parameters were obtained in the energy range up to 1000 eV. The table of the resonance parameters is given with some statistical properties of the parameters. Tabulated and graphical comparisons between the experimental data and the calculated cross sections are given. The results are available in ENDF/B-V format and will be proposed for the evaluated data libraries JEF2 and ENDF/B-VI.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Centre d'Etudes Nucleaires de Cadarache, France.

2.28

R-MATRIX ANALYSIS OF THE ${}^{241}\text{Pu}$ NEUTRON CROSS SECTIONS IN THE ENERGY RANGE THERMAL TO 300 eV

H. Derrien* G. de Saussure

(Abstract of ORNL/TM-11123, April 1989)

The report is a description of the analysis of the ${}^{241}\text{Pu}$ neutron cross sections in the resolved resonance region at Oak Ridge National Laboratory (ORNL) using the multilevel-multichannel Reich-Moore code SAMMY. The resonance parameters were obtained in the energy range 0 to 300 eV. The table of the resonance parameters is given with some statistical properties of the parameters. Tabulated and graphical comparison between the experimental data and the calculated cross sections are given. The results are available in ENDF/B-V format and will be proposed for the evaluated data library JEF2 and ENDF/B-VI.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Centre d'Etudes Nucleaires de Cadarache, France.

2.29

R-MATRIX ANALYSES OF THE ^{235}U AND ^{239}Pu NEUTRON CROSS SECTIONS

H. Derrien* G. de Saussure
N. M. Larson† L. C. Leal‡
R. B. Perez

[Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30–June 3, 1988; Proc. S. Igarasi, Ed., Saiton Publishing Co., Ltd., pp. 83–86 (1988)]

The resonance parameter analysis code SAMMY was used to perform consistent resonance analyses of several ^{235}U and ^{239}Pu fission and capture cross section and transmission measurements up to 110 eV for ^{235}U and up to 1 keV for ^{239}Pu . The method of analysis, the measurement selection, and the results are briefly outlined in this paper.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.30

REICH-MOORE AND ADLER-ADLER REPRESENTATIONS OF THE ^{235}U CROSS SECTIONS IN THE RESOLVED RESONANCE REGION

G. de Saussure L. C. Leal*
R. B. Perez

(Abstract of paper to be presented at the International Conference on the Physics of Reactors: Operation, Design, and Computation, Marseille, France, April 23–26, 1990)

Alternative representations of the evaluation of the ^{235}U neutron cross sections in the resolved resonance range are discussed. The resonance analysis of the cross sections was done with the code SAMMY, using the Reich-Moore formalism. We have used the POLLA option of the code WHOPPER of Hwang to transform the Reich-Moore resonance parameters describing the ^{235}U cross sections into equivalent Adler-Adler parameters.

We have also used the POLLY option of the code WHOPPER to obtain the expansion in momentum space of the cross-section representations

and verified that the cross sections computed with the multiple parameters were rigorously equal to the cross sections computed with the Reich-Moore parameters.

We believe that the accurate representation of the ^{235}U evaluations with Adler-Adler parameters and the exact representation with multiple parameters in momentum space should provide useful alternatives to the Reich-Moore formalism for reactor codes, like Mc^2 , which use the Voigt profiles and J-functions. The evaluated Reich-Moore resonance parameters, and the equivalent Adler-Adler and multiple parameter sets, are available from the authors.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*University of Tennessee, Knoxville, TN.

2.31

A NEW RESONANCE-REGION EVALUATION OF NEUTRON CROSS SECTIONS FOR U-235

G. de Saussure L. C. Leal*
R. B. Perez N. M. Larson†
M. S. Moore‡

[Abstract of *Nucl. Sci. Eng.* 103(2), 109 (1989); also paper presented at the 1988 International Reactor Physics Conference, Jackson Hole, WY, September 18–21, 1988; Proc. Vol. 1, pp. 293–302 (1988)]

This paper describes a new evaluation of the "resolved resonance range" for the neutron cross sections of ^{235}U . Up to 110 eV the evaluation is based on an R-matrix analysis of several fission, capture and transmission measurements. Above 110 eV levels are not resolved anymore so that many resonances are missed; from 110 to 500 eV most of the important resonances can be identified and analyzed so that the cross section and transmission data are well represented by the proposed parameters. From 500 to 2250 eV fictitious parameters are provided which describe fairly well the results of thick sample transmission measurements and recent fission cross-section data. We believe that such a parameterization is likely to yield a better approximation of resonance self-shielding than the current ENDF/B-V unresolved resonance treatment.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.32

**UNCERTAINTIES OF THE ENDF/B-V
²³⁸U UNRESOLVED RESONANCE
 PARAMETERS IN THE RANGE
 $4 \text{ keV} \leq E \leq 45.18 \text{ keV}$
 (MAT=1398, MF=2, MT=251)**

G. de Saussure J. H. Marable*

[Abstract of Nucl. Sci. Eng. 101, 285-292 (1989)]

It is a common practice in ENDF/B to represent neutron cross sections in the unresolved resonance region by specifying the average values and distribution laws of resonance parameters. This formalism allows the calculation of resonance self-shielding and of the variation of resonance self-shielding with temperature, two important reactor parameters. For many applications it is necessary to estimate the uncertainties in these model average resonance parameters. A possible approach to derive such uncertainties is described, using as an example the ENDF/B-V representation of ²³⁸U in the range from 4 to 45 keV.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Consultant.

2.33

**STOCHASTIC NUCLEAR REACTION
 THEORY: BREIT-WIGNER
 NUCLEAR NOISE**

G. de Saussure R. B. Perez

[Abstract of paper in *Noise and Nonlinear Phenomena in Nuclear Systems*, Series B: Physics Vol. 192, pp. 457-461, proceedings of the NATO Advanced Research Workshop, Universidad Politecnica de Valencia, Spain, May 23-27, 1988, J. L. Munoz Cobo and F. C. Difilippo, Eds., Plenum Press, NY (1989)]

Our present understanding of neutron-nucleus interaction is largely based on Bohr's statistical compound nucleus model. However, theoretical developments based on quantum corrections to Bohr's model, together with considerable improvements in neutron spectroscopy have predicted and revealed the presence of marked fluctuations in the neutron cross sections of both fissile and fertile nuclei. These fluctuations are wider than the sharp resonances associated with the compound nucleus levels and narrower than the broad structure due

to the energy dependence of the neutron penetration coefficients. They, in fact, represent departures from the statistical compound nucleus model in localized energy regions, leading to an intermediate structure which is not predicted by Bohr's model. The observed enhancement of the neutron cross section is due to the presence of doorway states in the neutron channel or in the fission channels in fissile nuclei. The understanding and detection of this intermediate structure is of great relevance both in nuclear reaction theory and for the calculation of nuclear reactor parameters.

The purpose of this paper is the application of various statistical tests for the detection of the intermediate structure, which lies immersed in the Breit-Wigner "noise" arising from the superposition of many compound nucleus resonances. To this end, neutron capture cross sections are constructed by Monte Carlo simulations of the compound nucleus, hence providing the "noise" component. In a second step intermediate structure is added to the Breit-Wigner noise. The performance of the statistical tests in detecting the intermediate structure is evaluated using mocked-up neutron cross sections as the statistical samples. Afterwards, the statistical tests are applied to actual nuclear cross section data.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.34

**EVALUATED CROSS SECTIONS
 FOR NEUTRON SCATTERING
 FROM NATURAL CARBON BELOW
 2 MeV INCLUDING R-MATRIX
 FITS TO C-13 RESONANCES**

C. Y. Fu

[Abstract of Nucl. Sci. Eng. (in press)]

The ENDF/B-V differential cross sections for neutron scattering from natural carbon below 2 MeV, recommended as standards for measurements and based on an R-matrix analysis for ¹²C using natural carbon data, are revised to include ¹³C resonances for high-resolution applications. The recommended ¹³C cross sections are also based on an R-matrix analysis of the available data. The 0.1529-MeV and the 1.736-MeV resonances rise above the natural carbon background by 7% and 1%, respectively. The angular distribu-

tions of the elastically scattered neutrons from ^{13}C are generated by the R-matrix theory. The final recommended cross sections and Legendre coefficients of angular distributions for natural carbon, adopted for ENDF/B-VI, are tabulated.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.35

USE OF SAMMY IN RESONANCE ANALYSIS OF NEUTRON DATA

N. M. Larson*

(Abstract of oral presentation presented at GELINA, Geel, Belgium, November 16, 1987)

At ORELA analysis of resonance neutron cross-section data is generally performed via the computer code SAMMY. Designed for use on the ORELA VAX and/or FPS (Floating Point Systems) computers, the code is being modified for use on the IBM 4381/P02 system at GELINA in Geel, Belgium. The various features of SAMMY and their use in the data analysis process will be described and the process of running the code will be discussed.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.36

UPDATED USERS' GUIDE FOR SAMMY: MULTILEVEL R-MATRIX FITS TO NEUTRON DATA USING BAYES' EQUATION

N. M. Larson*

(Abstract of ORNL/TM-9179/R2, June 1989)

In 1980 the multilevel multichannel R-matrix code SAMMY was released for use in analysis of neutron data at the Oak Ridge Electron Linear Accelerator. Since that time, SAMMY has undergone significant modifications: (1) User-friendly options have been incorporated to streamline common operations and to protect a run from common user errors. (2) The Reich-Moore formalism has been extended to include an optional logarithmic parameterization of the external R-matrix, for which any or all parameters may be varied. (3) The ability to vary sample thickness, effective temperature, matching radius,

and/or resolution-broadening parameters has been incorporated. (4) To avoid loss of information (i.e., computer round-off errors) between runs, the "covariance file" now includes precise values for all variables. (5) Unused but correlated variables may be included in the analysis.

Because of these and earlier changes, the 1980 SAMMY manual is now hopelessly obsolete. This report is intended to be complete documentation for the current version of SAMMY. Its publication in looseleaf form will permit updates to the manual to be made concurrently with updates to the code itself, thus eliminating most of the time lag between update and documentation.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.37

RESONANCE PARAMETER ANALYSIS WITH SAMMY

N. M. Larson* F. G. Perey

(Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saikon Publishing Co., Ltd., pp. 573-576 (1988))

The multilevel R-matrix computer code SAMMY has evolved over the past decade to become an important analysis tool for neutron data. SAMMY uses the Reich-Moore approximation to the multilevel R-matrix and includes an optional logarithmic parameterization of the external R-function. Doppler broadening is simulated either by numerical integration using the Gaussian approximation to the free gas model or by a more rigorous solution of the partial differential equation equivalent to the exact free gas model. Resolution broadening of cross sections and derivatives also has new options that more accurately represent the experimental situation. SAMMY treats constant normalization and some types of backgrounds directly and treats other normalizations and/or backgrounds with the introduction of user generated partial derivatives. The code uses Bayes' method as an efficient alternative to least squares for fitting experimental data. SAMMY allows virtually any parameter to be varied and outputs values, uncertainties, and covariance matrix for all varied parameters. Versions of SAMMY exist for VAX, FPS, and IBM computers.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.38

**URR COMPUTER CODE: A CODE TO
CALCULATE RESONANCE NEUTRON
CROSS-SECTION PROBABILITY
TABLES, BONDARENKO SELF-
SHIELDING FACTORS, AND SELF-
INDICATION RATIOS FOR FISSILE
AND FERTILE NUCLIDES**

L. C. Leal* G. de Saussure
R. B. Perez

(Abstract of ORNL/TM-11297, August 1989)

The URR computer code has been developed to calculate cross-section probability tables, Bondarenko self-shielding factors, and self-indication ratios for fertile and fissile isotopes in the unresolved resonance region. Monte Carlo methods are utilized to select appropriate resonance parameters and to compute the cross sections at the desired reference energy.

The neutron cross sections are calculated by the single-level Breit-Wigner formalism with s -, p -, and d -wave contributions. The cross-section probability tables are constructed by sampling the Doppler broadened cross-section.

The various shield-shielded factors are computed numerically as Lebesgue integrals over the cross-section probability tables.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.39

**ANALYSIS OF THE U-235 NEUTRON
CROSS SECTIONS IN THE RESOLVED
RESONANCE RANGE**

L. C. Leal* G. de Saussure
R. B. Perez

(Abstract of paper presented at the American Nuclear Society and National Bureau of Standards Conference on Fifty Years with Nuclear Fission, Gaithersburg, MD, April 26-28, 1989)

Using recent high-resolution measurements of the neutron transmission of ^{235}U and the spin-separated fission cross-section data of Moore *et al.*, a multilevel analysis of the ^{235}U neutron cross sections was performed up to 300 eV. The Dyson Method Δ_3 statistics were used to help locate small levels above 100 eV where resonances are not

clearly resolved even in the best resolution measurements available. The statistical properties of the resonance parameters are discussed.

Research sponsored by U.S. DOE Office of Energy Research, Nuclear Physics.

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2.40

**R-MATRIX ANALYSIS
OF THE ^{235}U NEUTRON
CROSS SECTIONS**

L. C. Leal* G. de Saussure
R. B. Perez

(Abstract *Trans. Am. Nucl. Soc.* 56, 587 (1988))

The ENDF/B-V representation of the ^{235}U neutron cross sections in the resolved resonance region is unsatisfactory: below 1 eV, the cross sections are given by "smooth files" (file 3) rather than by resonance parameters; above 1 eV, the single-level formalism used by ENDF/B-V necessitates a structured file 3 contribution consisting of ≥ 1300 energy points; furthermore, information on level spins has not been included. Indeed, the ENDF/B-V ^{235}U resonance region is based on an analysis done in 1970 for ENDF/B-III and therefore does not include the results of high-quality measurements done in the past 18 yr. This paper presents the result of an R-matrix multilevel analysis of recent measurements as well as older data. The analysis also extends the resolved resonance region from its ENDF/B-V upper limit of 81 to 110 eV.

The resonance analysis code SAMMY was used to perform a consistent resonance parameter analysis of several ^{235}U neutron fission and capture cross-section and transmission measurements and of the spin separated data obtained from an analysis of the polarized neutron target measurements.

The SAMMY program uses the multilevel R-matrix Reich-Moore formalism and leads to a physically sound representation of the neutron cross sections in the resonance region. The Bayesian approach, which includes the direct introduction of experimental uncertainties, such as on sample thicknesses, broadening parameters, etc., allows the successive incorporation of new data in a consistent manner. The option of searching on sample thicknesses, effective sample temperature, and the parameters of the

instrumental resolution function, all consistent with predetermined uncertainty limits, leads to realistic parameter uncertainties and covariance matrices. Recent modification of the SAMMY program also permits a consistent Bayesian fit of the spin-separated fission data. The cross sections of ^{235}U up to 110 eV were represented by a set of 260 resonances with two open fission channels in each spin state.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.41

STATISTICAL PROPERTIES OF THE ^{235}U RESONANCE PARAMETERS UP TO 300 eV

L. C. Leal* G. de Saussure
R. R. Winters† R. B. Perez

[Abstract of *Trans. Am. Nucl. Soc.* 59, 341 (1989)]

An accurate resonance analysis of the ^{235}U neutron cross sections up to 300 eV is in progress for the ENDF/B-VI files. A detailed discussion of the data base and a description of the method of resonance analysis have been given elsewhere. The purpose of this paper is to report on the statistical properties of the ^{235}U resonance parameters and compare our results with those of previous analyses.

The present analysis is an improvement over previous analyses because of the combined use of recent spin-separated and high-energy resolution data with the Δ_3 statistics, which facilitates the resonance analysis and improves its physical content.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.42

RESONANCE STRUCTURE IN THE FISSION OF ($^{235}\text{U} + n$)

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G. de Saussure R. B. Perez
N. M. Larson‡

(Abstract of paper presented at the International Conference Fifty Years of Research in Nuclear Fission, Berlin, West Germany, April 3-7, 1989)

A new multilevel reduced R-matrix analysis of the neutron-induced resonance cross sections of ^{235}U has been carried out. We used as a constraint in the analysis the angular anisotropy measurements of Pattenden and Postma, obtaining a Bohr-channel (or J, K channel) representation of the resonances in a two-fission vector space for each spin state. Hambach *et al.*, have reported definitive measurements of the mass- and kinetic-energy distributions of fission fragments of ($^{235}\text{U} + n$) in the resonance region and analyzed their results according to the fission-channel representation of Brosa *et al.*, extracting relative contributions of the two asymmetric and one symmetric Brosa fission channels. We have explored the connection between Bohr-channel and asymmetric Brosa-channel representations. The results suggest that a simple rotation of coordinates in channel space may be the only transformation required; the multilevel fit to the total and partial cross sections is invariant to such a transformation.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.43

RFUNC - A CODE TO ANALYZE DIFFERENTIAL ELASTIC- SCATTERING DATA

F. G. Perey

(Abstract of ORNL/TM-11112, March 1989)

The code RFUNC is used at ORELA to analyze high resolution differential elastic scattering data from spin zero nuclides in the resonance energy region. This report presents the

real R-function formalism used in RFUND and gives details of how the finite size corrections are currently made. Appendix A describes the input to the code RFUNC. Appendix B describes the input to a utility code MAKPA that transforms a resonance parameter file in SAMMY format into a resonance parameter file in RFUNC format. Appendix C describes the input to an adjunct code RFUNCXT that generates the contributions to the total cross section from resonances of different orbital and total angular momenta. The FORTRAN listing of the code RFUNC is given in Appendix D.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.44

ON THE UNRESOLVED RESONANCE REGION REPRESENTATION OF NEUTRON INDUCED CROSS SECTIONS

R. B. Perez G. de Saussure
L. C. Leal* Roger Macklin*

[Abstract of paper presented at the 1988 International Reactor Physics Conference, Jackson Hole, WY, September 18-21, 1988; Proc. Vol. II, pp. 183-188 (1988)]

In this work we review the unresolved resonance region formalism in the light of the availability of new high-energy resolution measurements.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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CROSS SECTION EVALUATION AND MODELING

2.45

SCINFUL: A MONTE CARLO BASED COMPUTER PROGRAM TO DETERMINE A SCINTILLATOR FULL ENERGY RESPONSE TO NEUTRON DETECTION FOR E_n BETWEEN 0.1 AND 80 MeV: USER'S MANUAL AND FORTRAN PROGRAM LISTING

J. K. Dickens

(Abstract of ORNL-6462, March 1988)

This document provides a complete listing of the FORTRAN program SCINFUL, a program designed to provide a calculated full response anticipated for either an NE-213 (liquid) scintillator or an NE-110 (solid) scintillator. The incident design neutron energy range is 0.1 to 80 MeV. Preparation of input to the program is discussed as are important features of the output. Also included is a FORTRAN listing of a subsidiary program applicable to the output of SCINFUL. This user-interactive program is named SCINSPEC from which the output of SCINFUL may be reformatted into a standard spectrum form involving either equal light-unit or equal proton-energy intervals. Examples of input to this program and corresponding output are given.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.46

SCINFUL: A MONTE CARLO BASED COMPUTER PROGRAM TO DETERMINE A SCINTILLATOR FULL ENERGY RESPONSE TO NEUTRON DETECTION FOR E_n BETWEEN 0.1 AND 80 MeV: PROGRAM DEVELOPMENT AND COMPARISONS OF PROGRAM PREDICTIONS WITH EXPERIMENTAL DATA

J. K. Dickens

(Abstract of ORNL-6463, April 1988)

This document provides a discussion of the development of the FORTRAN Monte Carlo program SCINFUL (for scintillator full response), a program designed to provide a calculated full response anticipated for either an NE-213 (liquid) scintillator or an NE-110 (solid) scintillator. The program may also be used to compute angle-integrated spectra of charged particles (p , d , t , ^3He , and α) following neutron interactions with ^{12}C . Extensive comparisons with a variety of experimental data are given. There is generally overall good agreement ($\leq 10\%$ differences) of results from SCINFUL calculations with measured detector efficiencies for the incident design neutron energy range of 0.1 to 80 MeV. Calculations of detector responses, i.e., $N(E_r)$ vs E_r where E_r is

the response pulse height, reproduce measured detector responses with an accuracy which, at least partly, depends upon how well the experimental configuration is known. For $E_n \leq 16$ MeV and for $E_r \geq 15\%$ of the maximum pulse height response, calculated spectra are within $\pm 5\%$ of experiment on the average. For E_n up to 50 MeV similar good agreement is obtained with experiment for $E_r \geq 30\%$ of maximum response. For E_n up to 75 MeV the calculated shape of the response agrees with measurements, but the calculation underpredicts the measured response by up to 30%.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.47

A SIMPLIFIED UNIFIED HAUSER-FESHBACH/PRE-EQUILIBRIUM MODEL FOR CALCULATING DOUBLE DIFFERENTIAL CROSS SECTIONS

C. Y. Fu

[Abstract of paper presented at the NEANDC Specialists' Meeting on Pre-equilibrium Reactions, Semmerling, Austria, February 10-12, 1988; Proc. pp. 285-291 (1988)]

A unified Hauser-Feshbach/Pre-Equilibrium model is extended and simplified. The extension involves the addition of correlations among states of different total quantum numbers (J and J') and the introduction of consistent level density formulas for the H-F and the P-E parts of the calculation. The simplification, aimed at reducing the computational costs, is achieved mainly by keeping only the off-diagonal terms that involve strongly correlated $2p-1h$ states. A correlation coefficient is introduced to fit the experimental data. The model has been incorporated into the multistep H-F model code TNG. Calculated double differential (n, xn) cross sections at 14 and 25.7 MeV for iron, niobium, and bismuth are in good agreement with experiments. In use at ORNL and JAFRI, the TNG code in various stages of development has been applied with success to the evaluation of double differential (n, xn) cross sections from 1 to 20 MeV for the dominant isotopes of chromium, manganese, iron, nickel, copper, and lead.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.48

APPROXIMATION OF PRECOMPOUND EFFECTS IN HAUSER-FESHBACH CODES FOR CALCULATING DOUBLE DIFFERENTIAL (n, xn) CROSS SECTIONS

C. Y. Fu

[Abstract of Nucl. Sci. Eng. 100, 61 (1988)]

A simplified method for approximating precompound nuclear reaction effects in Hauser-Feshbach codes for the calculation of double differential (n, xn) cross sections is presented. The method is developed from an existing quantum mechanical formula of unified compound and precompound reaction theories. The compound part of the unified formula is made identical to that of Hauser and Feshbach 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. Calculated double differential (n, xn) cross sections at 14 and 26 MeV for iron, niobium, and bismuth are shown to be in good agreement with the available experimental data. The method at various stages of development has been applied with success to the generation of evaluated files of double differential (n, xn) cross sections from 5 to 20 MeV for the major isotopes of chromium, manganese, iron, nickel, and copper.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.49

PAIRING CORRECTIONS AND SPIN CUTOFF FACTORS IN EXCITON LEVEL DENSITIES FOR TWO KINDS OF FERMIONS

C. Y. Fu

[Abstract of paper presented at the Sixth Coordination Meeting for the Program to Meet Nuclear Data Needs for Fusion Energy, Athens, OH, September 19-21, 1989]

Pairing corrections in particle-hole (exciton) state-density formulas used in precompound nuclear reaction theories are, strictly speaking, dependent on the nuclear excitation energy U and the exciton number n . A general formula for

(U, n)-dependent pairing corrections has been derived in an earlier paper for the exciton state-density formula for one kind of Fermion. In the present paper, a similar derivation is made for two kinds of Fermions. In this formulation, it is assumed that neutrons and protons occupy different sets of single particle states. It is shown that the constant-pairing-energy correction used in standard state-density formulas, such as U_0 in Gilbert and Cameron, is a limiting case of the present general (U, n)-dependent results. Spin cutoff factors with pairing effects are obtained in the same derivations, thereby defining the exciton level-density formula for two kinds of Fermions. Numerical examples are shown to explain the difference in these quantities between the one-Fermion and two-Fermion formulations.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.50

STATUS OF THEORIES USED FOR CALCULATIONS OF LONG-LIVED ACTIVATION CROSS SECTIONS

C. Y. Fu

(Abstract of paper presented at the IAEA Consultants' Meeting on Cross Sections for the Generation of Long-lived Radionuclides, Argonne, IL, September 11-12, 1989)

For activation reactions that produce long-lived radionuclides, the standard model codes for calculating the cross sections are multistep Hauser-Feshbach with pre-equilibrium reaction and gamma-ray cascade capabilities. The nuclear theories required in such codes include optical models, gamma-ray strength functions, total and exciton level-density theories, and pre-equilibrium models. Recent advances and perceived weaknesses in these theories and the relevant parameters are reviewed through the examples of the $^{58}\text{Ni}(n, \gamma)^{59}\text{Ni}$ (7.5×10^4 y), $^{63}\text{Cu}(n, p)^{63}\text{Ni}$ (100 y), and $^{206}\text{Pb}(n, 2n)^{205}\text{Pb}$ (1.4×10^7 y) reactions. In addition, it is shown that accuracies of the calculated results depend on the number of discrete levels used and on the correct assignments of their spins and parities.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.51

A REVIEW OF ACTIVATION CROSS SECTIONS IN THE ENDF/B-VI GENERAL PURPOSE FILES OF Cr, Fe, Ni, Cu, AND Pb

C. Y. Fu

(Abstract of paper presented at the NEANDC Specialist's Meeting on Neutron Activation Cross Sections for Fission and Fusion Energy Applications, Argonne, IL, September 13-15, 1989)

Isotopic evaluations for $^{50,52,53,54}\text{Cr}$, $^{54,56,57,58}\text{Fe}$, $^{58,60,61,62,64}\text{Ni}$, $^{63,65}\text{Cu}$, and $^{206,207,208}\text{Pb}$ are included in ENDF/B-VI for the first time. These general purpose files, all by the ORNL evaluation group, naturally account for many activation cross sections. In this review, we first took the 33 activation reactions for these materials from the high priority CSEWG list for fusion reactor design and checked for their presence in the general purpose files. It was immediately obvious that an evaluation for ^{204}Pb , omitted due to its low abundance, needs to be added as it would contain three high priority activation cross sections, namely, $^{204}\text{Pb}(n, \gamma)$, (n, p) , and $(n, 2n)$. Among the three, $^{204}\text{Pb}(n, \gamma)^{205}\text{Pb}$, having the very long half life of 14 million years, is particularly important for consideration of radioactive waste disposal. Another reaction with long-lived (0.3 million years) daughter, $^{61}\text{Ni}(n, 2p)^{60}\text{Fe}$, ignored in the general purpose evaluation because of its small cross section, should also be added. The remainder of the activation cross sections are reviewed in terms of the experimental data base and the evaluation methods. Most of them have been significantly improved over ENDF/B-V through either detailed resonance analysis (e.g., capture cross sections) or least-squares averaging (e.g., dosimetry reactions).

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.52

ENDF/B-VI EVALUATIONS FOR ISOTOPES OF Cr, Fe, Ni, AND Cu, AND FOR NATURAL Pb

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

[Abstract of paper presented at the ANS Eighth Topical Meeting on Technology of Fusion Energy, Salt Lake City, UT, October 9-13, 1988; *Fusion Tech.* 15(2), 453 (March 1989)]

ENDF/B-VI is the first version of the ENDF library to pay particular attention to fusion data needs. Structural materials exist in significant amounts in various locations of proposed fusion reactors. Thus, the evaluations must be adequate to meet a wide variety of needs, including neutron transport, heating, radiation damage, etc. Much work, both experimental and theoretical, has gone into the structural material evaluations, and this paper highlights the major improvements over ENDF/B-V.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.53

DESCRIPTION OF EVALUATION OF ²⁰⁸Pb PERFORMED FOR ENDF/B-VI

D. C. Larson C. Y. Fu

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987]

An evaluation of data for neutron induced reactions on natural lead was performed for ENDF/B-VI and is briefly reviewed. The evaluation is based on experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data. Uncertainty files are included for the major cross sections. Much of the present evaluation is taken over from ENDF/B-IV and ENDF/B-V; emphasis is placed on updates for ENDF/B-VI.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.54

SOME NOTES ON THE CALCULATION OF ENERGY-ANGLE CORRELATED DISTRIBUTIONS WITH TNG AND THEIR REPRESENTATION IN FILE 6 FORMATS

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

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987; Proc. p. 220, V. Goulo, Ed. (August 1989)]

The model code TNG has been extensively used in evaluation work of structural materials for ENDF/B-VI performed at Oak Ridge National Laboratory. A new aspect of ENDF/B-VI is the use of File 6 formats for energy-angle correlated data. Such data are generally calculated, anchored by experimental data. In this informal note we outline how the TNG results are calculated and entered in the File 6 formats.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.55

DESCRIPTION OF EVALUATION FOR ^{54,56,57,58}Fe PERFORMED FOR ENDF/B-VI

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

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987; Proc. p. 204, V. Goulo, Ed. (August 1989)]

Isotopic evaluations for ^{54,56,57,58}Fe performed for ENDF/B-VI are briefly reviewed. The evaluations are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. A detailed evaluation is given for ⁵⁶Fe and results of calculations for the major reactions are used for evaluations of the minor isotopes, with

particular attention paid to inelastic scattering to the low-lying levels in ^{57}Fe .

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.56

**DESCRIPTION OF EVALUATION
FOR $^{58,60,61,62,64}\text{Ni}$
PERFORMED FOR ENDF/B-VI**

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

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987; Proc. p. 195, V. Goulo, Ed. (August 1989)]

Isotopic evaluations for $^{58,60,61,62,64}\text{Ni}$ performed for ENDF/B-VI are briefly reviewed. The evaluations are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. Detailed evaluations are given for $^{58,60}\text{Ni}$, and results of calculations for the major reactions are used for evaluations of the minor isotopes.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.57

**DESCRIPTION OF EVALUATION
FOR $^{63,65}\text{Cu}$ PERFORMED
FOR ENDF/B-VI**

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

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987; Proc. p. 212, V. Goulo, Ed. (August 1989)]

Isotopic evaluations for $^{63,65}\text{Cu}$ performed for ENDF/B-VI are briefly reviewed. The evalua-

tions are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. Full evaluations are given for $^{63,65}\text{Cu}$.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.58

**DESCRIPTION OF EVALUATION
FOR $^{50,52,53,54}\text{Cr}$
PERFORMED FOR ENDF/B-VI**

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

[Abstract of paper presented at the IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, Austria, November 16-18, 1987; Proc. p. 187, V. Goulo, Ed. (August 1989)]

Isotopic evaluations for $^{50,52,53,54}\text{Cr}$ performed for ENDF/B-VI are briefly reviewed. The evaluations are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. Detailed evaluations are given for $^{52,53}\text{Cr}$, and results of calculations for reactions with large cross sections are used for evaluations of the minor isotopes.

Research sponsored by U.S. DOE Division of Nuclear Physics.

*Computing and Telecommunications Division.

2.59

STRUCTURAL AND SHIELDING MATERIAL EVALUATIONS FOR ENDF/B-VI

D. C. Larson P. G. Young *

[Abstract of *Trans. Am. Nucl. Soc.* 60, 606 (1989)]

Following completion of ENDF/B-V several problems and shortcomings were apparent in evaluations for important shielding and structural materials. Lack of energy balance was a new problem which arose from use of nonisotopic evaluations and lack of checking by evaluators. Discrepancies between evaluated and measured neutron emission spectra resulted from omission of a precompound component in the theoretical analysis of the data. Difficulties experienced by users in obtaining accurate KERMA and radiation damage function quantities were due primarily to format shortcomings. These problems and potential solutions were discussed by the General Purpose Evaluation Subcommittee of CSEWG in the early 1980's. Improvements in formats and nuclear model codes, and use of isotopic evaluations were some of the techniques implemented to insure improved evaluations for ENDF/B-VI. New developments in experimental techniques provided improved data upon which to benchmark the evaluations. In this paper we outline major improvements and provide a list of materials upgraded for ENDF/B-VI.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.60

TEST OF THE ENDF/B UNRESOLVED RESONANCE FORMALISM FOR U-235

L. C. Leal* G. de Saussure
R. B. Perez R. Q. Wright†[Abstract of *Trans. Am. Nucl. Soc.* 60, 620 (1989)]

It is common practice in ENDF/B to represent neutron cross sections in the unresolved resonance region by specifying the average values and distribution laws of resonance parameters. This formalism allows the calculation of resonance self-shielding and of its variation with temperature.

The purpose of this paper is to present a test of the validity of the formalism by comparing self-shielding factors computed with the ENDF/B unresolved formalism, with values computed with the resolved resonance parameters recently evaluated for the neutron cross sections of U-235 up to 500 eV.

Research sponsored by U.S. DOE Division of Nuclear Physics.

* University of Tennessee, Knoxville, TN.

† Computing and Telecommunications Division.

2.61

COVARIANCE DATA FOR ENDF/B-VI

R. W. Peelle

[Abstract of *Trans. Am. Nucl. Soc.* 60, 608 (1989)]

Since the development of ENDF/B-V, more experimenters have included covariance information with their results, and techniques for data evaluation that include covariance information that have been developed. For ENDF/B-VI these developments and the extended ENDF-6 covariance formats make possible inclusion of covariance data for pressure vessel dosimetry, fusion reactor activation, fast reactor core physics, etc.

Covariance data for cross sections that are output from model or fitting codes can be represented implicitly in ENDF/B-6 formats in terms of the model parameter covariance matrix and the tabulated derivatives of cross sections with respect to the model parameters. Also for ENDF/B-VI, all new covariance evaluations of smooth cross sections will include a minimum variance component to increase validity and relieve numerical problems encountered by data-base adjusters.

ENDF/B-VI evaluated covariance files can meet most requirements for uncertainty propagation and data adjustment because of broadened format capabilities and because of the increased experience with covariance data. However, the first release of ENDF/B-VI will not contain all the needed information.

The author acknowledges the large contributions by members of the CSEWG Covariance Subcommittee, Doug Muir in particular.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.62

NEUTRON STANDARD DATA

R. W. Peelle H. Conde*

[Abstract of paper presented at the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988; Proc. S. Igarasi, Ed., Saiton Publishing Co., Ltd., pp. 1005-1012 (1988)]

The neutron standards are reviewed with emphasis on the evaluation for ENDF/B-VI. Also discussed are the neutron spectrum of ^{252}Cf spontaneous fission, activation cross sections for neutron flux measurement, and standards for neutron energies greater than 20 MeV. Recommendations are made for future work.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.63

EXTENDED COVARIANCE DATA FORMATS FOR THE ENDF/B-VI DIFFERENTIAL DATA EVALUATION

R. W. Peelle D. W. Muir*

[Abstract of paper presented at the Specialists' Meeting on the Application of Critical Experiments and Operating Data to Core Design via Formal Methods of Cross Section Data Adjustment, Jackson Hole, WY, September 23-24, 1988; Proc. NEACRP-L-307, pp. 305-315 (1988)]

The ENDF/B-V included cross section covariance data, but covariances could not be encoded for all the important data types. New ENDF-6 covariance formats are outlined including those for cross-file (MF) covariances, resonance parameters over the whole range, and secondary energy and angle distributions. One "late entry" format encodes covariance data for cross sections that are output from model or fitting codes in terms of the model parameter covariance matrix and the tabulated derivatives of cross sections with respect to the model parameters. Another new format yields multigroup cross section variances that increase as the group width decreases. When evaluators use the new format, the files can be processed and used for improved uncertainty propagation and data combination.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.64

COVARIANCES OF PHYSICAL CONSTANTS

F. G. Perey

(Abstract of oral presentation presented at the NCSL Annual Conference and Symposium, Washington, DC, August 14-18, 1988)

In many modern engineering-system studies the uncertainties in some key performance parameters are dominated by the uncertainties in the physical constants of the components of the system and are very strongly affected by the covariances of these physical constants. About 10 years ago this was realized as the case for fast nuclear reactor studies, and the data bases were modified to include covariances of the key physical constants. Experimentalists who provide nuclear data for applications are now increasingly describing the covariances in their measured data. The problems of determining and reporting the complete covariance matrix of measured data will be discussed.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.65

A STOCHASTIC METHOD FOR NUCLEAR POWER PLANT DIAGNOSIS

R. B. Perez R. T. Wood*

[Abstract of paper in *Noise and Nonlinear Phenomena in Nuclear Systems*, Series B: Physics Vol. 192, pp. 451-456, proceedings of the NATO Advanced Research Workshop, Universidad Politecnica de Valencia, Spain, May 23-27, 1988, J. L. Munoz Cobo and F. C. Difilippo, Eds., Plenum Press, NY (1989)]

The value of using neutron noise descriptors, especially the power spectral densities (PSDs) of ex-core detectors, to monitor core barrel motion and fuel element vibrations in pressurized water reactors (PWRs) is well established. In the mid-frequency range (1-20 Hz), PWR neutron noise is dominated by vibration peaks in the neutron PSD that result from the motion of reactor internals. A qualitative examination of such descriptors from a 1150-MWE Westinghouse PWR plant, revealed significant changes in the plant's noise signature (PSD) as its first fuel cycle proceeded. The purpose of this work is to use a mathematical model of the interaction between small mechanical mo-

tions and the core neutronics to provide a tool for quantitative investigation of the PSD structure in the vibrational frequency range.

The purpose of neutron noise analysis is to provide information on plant conditions by the study of power traces from ex-core detectors. Due to the action of the coolant flow through the core and pump induced vibrations, the core barrel, which is bolted at the top of the reactor vessel, performs a pendular motion with a natural frequency determined by the mechanical parameters and constraints of the system. In addition, exter-

nal forces deform the cylindrical shape of the core barrel by inducing vibrational modes which are excited by the turbulence of the coolant flow and by the "table-shaker" effect of the core barrel motion. As a result of the various mechanical motions, the detector response will vary in a manner proportional to the importance function at the location of the disturbance.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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REVIEWS

2.66

ELECTRON LINEAR ACCELERATORS FOR FAST NEUTRON DATA MEASUREMENTS IN SUPPORT OF FUSION ENERGY APPLICATIONS

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O. A. Wasson† J. A. Harvey
D. C. Larson

[Abstract of Nucl. Sci. Eng. (in press)]

The interest in neutron data for energy applications has moved over the past 40 years from thermal/epithermal data to data in the eV/keV range (following or anticipating the general trend of technological development from thermal to fast fission reactors) to the MeV energy range to include fusion reactors. While the support for further improvement of data for fission reactors has weakened, the interest in neutron data for the development of terrestrial fusion power sources is rising, irrespective of the uncertain time schedule for the successful realization of such reactors. For this application, neutron data are mainly wanted from the keV region to about 14 MeV, which implies an extension of the energy region intensively investigated for fission reactor interests to substantially higher energies.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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2.67

DECAY HEAT MEASUREMENTS AND THE LOSS-OF-COOLANT ACCIDENT

J. K. Dickens

(Abstract of oral presentation given at the Department of Nuclear Engineering, University of Tennessee, Knoxville, TN, October 26, 1988)

About fifteen years ago serious concern about the consequences of an hypothetical loss-of-coolant accident at a Light Water Reactor prompted several experiments in the United States having the goal of measuring the heat source due to decay of fission products built up in the fuel. The experiment completed at ORNL is described and results from this experiment are compared with other U.S. experiments and with recently reported experiments done in Japan. The summation technique used to calculate this energy source, called "decay heat," is described. Application of these concepts to the accidents at Three-Mile Island and at Chernobyl is discussed.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.68

REACTOR SAFETY AND THE STATUS OF COMMERCIAL NUCLEAR POWER IN THE UNITED STATES

J. K. Dickens

(Abstract of oral presentation presented at Ohio University, Athens, Ohio, April 6-7, 1989)

Of all 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.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.69

NEUTRON RESEARCH AT THE OAK RIDGE ELECTRON LINEAR ACCELERATOR

J. K. Dickens

(Abstract of oral presentation presented at Ohio University, Athens, Ohio, April 6-7, 1989)

The Oak Ridge Electron Linear Accelerator (ORELA) is a multi-purpose facility used principally as a source of neutrons having energies between thermal and 80 MeV. A description of the facility will be presented. Research with neutrons at ORELA has been divided about equally between basic physics and applications. For the

former, for example, there have been recent studies leading to (a) an estimate of the age of the universe, and (b) some relationships between the optical model of neutron scattering and the shell model potential describing single-particle orbits in ^{40}Ca . For applied research effort has been directed toward obtaining data to be incorporated into the U.S. Evaluated Nuclear Data File (ENDF). Some current research in high-resolution in-beam gamma-ray spectroscopy, $(n, X\gamma)$ reactions, will be discussed, in particular some results for ^{53}Cr that are not yet understood from basic principles.

Research sponsored by U.S. DOE Division of Nuclear Physics.

2.70

ENDF/B-VI NUCLEAR DATA EVALUATIONS FOR FUSION APPLICATIONS

C. L. Dunford* D. C. Larson
P. G. Young†

(Abstract of paper presented at the ANS Eighth Topical Meeting on Technology of Fusion Energy, Salt Lake City, UT, October 9-13, 1988; *Fusion Tech.* 15(2), 429-439 (1989))

The next release of the ENDF/B data library planned for 1989 contains improved data evaluations of interest to the fusion neutronics community. New data formats permit inclusion of energy-angle correlated particle emission spectra and recoil nucleus energy spectra. Enhanced formats for covariance information have been developed. Many new isotopic evaluations will lead to improved energy conservation and kerma factor calculations. Improved nuclear model calculations will provide reliable particle emission data where experimental information is sparse. Improved Bayesian fitting codes will provide more accurate evaluations for data rich reactions such as $\text{Li}(n, nt)\alpha$. All of the most important fusion material evaluations contain these new features.

Research sponsored by U.S. DOE Division of Nuclear Physics.

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†Los Alamos National Laboratory, Los Alamos, NM.

2.71

**REPORTS ON NUCLEAR DATA
ACTIVITIES FOR THE DOE
NUCLEAR DATA COMMITTEE****D. C. Larson**

(Abstract of BNL-NCS-40911, p. 132, May 1988; and of BNL-NCS-42382, p. 136, April 1989)

These reports were prepared for the DOE Nuclear Data Committee and cover work performed at ORNL since January 1987 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 interest of DOE Nuclear Data Committee members and cannot claim completeness.

Research sponsored by U.S. DOE Division of Nuclear Physics.

Section 3
INTELLIGENT SYSTEMS

3.0. INTRODUCTION

R. C. Mann

The Center for Engineering Systems Advanced Research (CESAR) located in the Intelligent Systems Section continued to serve as a focal point for research in autonomous mobile robots and intelligent systems for unstructured operational environments. Publications indicate significant progress in several areas including machine learning, asynchronous production systems, and multi-sensor integration. Particular emphasis was placed on a thorough investigation of the robustness of robot hardware and software modules integrated into the CESAR mobile robot prototype HERMIES-IIB. This continuing effort underlined the importance of our continued commitment to mobile robot prototypes that can be used to generate quantitative data to characterize the performance of innovative methods for autonomous robots.

HERMIES-III, our latest mobile robot, was delivered and has been undergoing successful functionality tests. The robot features a seven degree-of-freedom research manipulator (CESARm) developed at ORNL, mounted on a platform with omni-directional steering. HERMIES-III can sense its three-dimensional surroundings through a laser range camera, stereo pairs of CCD cameras, and an array of sonar transducers. The on-board computer architecture includes a hypercube multi-processor, and multiple 68020 processors in four VME systems, a configuration that was designed to support full robot autonomy. The system represents a unique testbed for our research in combined mobility and manipulation, intelligent multi-sensor systems, concurrent computing, and machine reasoning. HERMIES-III and HERMIES-IIB also constitute a unique facility for pioneering research in multiple cooperating autonomous robots.

The section's modeling and simulation activities continued to address several domains, including energy-economy modeling, nuclear waste isolation, and radiation dosimetry. Automated sensitivity analysis represents one of the common themes in these diverse applications.

The Division's Human Factors Group joined our section during this reporting period. Significant accomplishments are reported in the areas of human-computer interactions, cognitive modeling of human operators in nuclear power plants, and human factors for usage of advanced instrumentation and controls in the nuclear industry. The challenging area of human interactions with mobile robots that have a high degree of autonomy may serve to enhance the integration of the human factors work into the section.

AUTONOMOUS MOBILE ROBOTS

3.1

ROBOT NAVIGATION RESEARCH AT CESAR

D. L. Barnett* G. de Saussure
S. S. Iyengar† F. G. Pin
A. Sabharwal† C. R. Weisbin

(Abstract of paper to be presented at the 18th IEEE Conference on Decision and Control, Tampa, FL, December 13-15, 1989)

A considerable amount of work has been reported on the problem of robot navigation in known static terrains. Algorithms have been proposed and implemented to search for an optimum path to the goal, taking into account the finite size and shape of the robot. Not as much work has been reported on robot navigation in unknown, unstructured, or dynamic environments.

A robot navigating in an unknown environment must explore with its sensors, construct an abstract representation of its global environment to plan a path to the goal, and update or revise its plan based on accumulated data obtained and processed in real-time.

The core of the navigation program for the CESAR robots is a production system developed on the expert-system-shell CLIPS which runs on an NCUBE hypercube onboard the robot. The production system can call on C-compiled navigation procedures. The production rules can read the sensor data and address the robot's effectors. The architecture was found efficient and flexible for the development and testing of the navigation algorithms; however, in order to process intelligently unexpected emergencies, it was found necessary to be able to control the production system through externally generated asynchronous data. This led to the design of a new asynchronous production system, APS, which is now being developed on the robot.

This paper will review some of the navigation algorithms developed and tested at CESAR and will discuss the need for the new APS and how it is being integrated into the robot architecture.

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

*Computing and Telecommunications Division.

†Louisiana State University, Baton Rouge, LA.

3.2

THE USE OF AN EXPERT SYSTEM FOR AUTONOMOUS ROBOT CONTROL

D. L. Barnett* G. de Saussure
P. F. Spelt

(Abstract of oral presentation presented at the American Society for Information Science Meeting, Ann Arbor, MI, May 15-18, 1988)

This paper describes the use of an expert system for control of HERMIES-IIIB, a mobile autonomous robot developed at the Center for Engineering Systems Advanced Research (CESAR). An expert system was considered desirable since the knowledge is in the form of rules that are easy to understand and modify. CLIPS, the expert system shell used in creating the knowledge base, accommodates access and management of information from a database through user-defined 'C' routines linked to the shell; therefore, the robot is able to make high-level decisions and to direct both data acquisition and information processing at a lower level. Each decision can be explained by retrieving the sequence of rules which led to that decision.

Future experiments are planned using an expanded version of the present expert system to demonstrate HERMIES' ability to diagnose and correct a process control problem. By experimentation the robot will learn a sequence of panel manipulations which will correct the diagnosed problem.

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

*Computing and Telecommunications Division.

3.3

ROBOT NAVIGATION RESEARCH USING THE HERMIES MOBILE ROBOT

D. L. Barnett* F. G. Pin

(Abstract of paper to be presented at the 1990 IEEE Conference on Robotics and Automation, Cincinnati, OH, May 13-18, 1990)

In recent years robot navigation has attracted much attention from researchers around the world. Not only are theoretical studies being simulated on

sophisticated computers, but many mobile robots are now used as test vehicles for these theoretical studies. Various algorithms have been perfected for navigation in a known static environment; but navigation in an unknown and dynamic environment poses a much more difficult problem for researchers. Many different methodologies have been developed for autonomous robot navigation, but each methodology usually has a particular type of environment in which it does not work well.

At the Center for Engineering Systems Advanced Research (CESAR) at Oak Ridge National Laboratory, research is focusing upon autonomous navigation in unknown and dynamic environments using the series of HERMIES mobile robots for testing algorithms. The research approach is one that has an expert system for high level planning interfaced with C routines for implementing the plans, and for quick processing of data requested by the expert system. In using this approach, the navigation is not restricted to one methodology since the expert system can activate a rule module for the methodology best suited for the current situation. Modules can be added as they are developed and tested and can be interfaced with the rule base. The rule base remains small, fast, efficient, and easy to understand and maintain. The C code is also small, easy to maintain, and modular with each routine performing a very specific function. Modules can be developed for navigating from a map, searching for a target, exploring, potential-field navigation, navigation using edge-detection, intense sensing of trouble spots, etc. This paper will address this particular approach that is now being researched and developed using the HERMIES-IIB robot.

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

*Computing and Telecommunications Division.

3.4

SPATIAL REASONING IN THE TREATMENT OF SYSTEMATIC SENSOR ERRORS

M. Beckerman J. P. Jones
R. C. Mann L. A. Farkas*
S. E. Johnston†

[Abstract of paper presented at the SPIE Conference on Sensor Fusion: Spatial Reasoning and Scene Interpretation, Cambridge, MA, November 6-11, 1988; Proc. Vol. 1003, pp. 338-349 (1988)]

In processing ultrasonic and visual sensor data acquired by mobile robots systematic errors can occur. The sonar errors include distortions in size and surface orientation due to the beam resolution and false echoes. The vision errors include, among others, ambiguities in discriminating depth discontinuities from intensity gradients generated by variations in surface brightness. In this paper we present a methodology for the removal of systematic errors using data from the sonar sensor domain to guide the processing of information in the vision domain, and vice versa. During the sonar data processing some errors are removed from 2D navigation maps through pattern analyses and consistent-labelling conditions, using spatial reasoning about the sonar beam and object characteristics. Others are removed using visual information. In the vision data processing vertical edge segments are extracted using a Canny-like algorithm and are labelled. Object edge features are then constructed from the segments using statistical and spatial analyses. A least-squares method is used during the statistical and spatial analyses. A least-squares method is used during the statistical analysis, and sonar range data are used in the spatial analysis.

Research sponsored by U.S. DOE Office of Nuclear Energy and by the Office of Technology Support Programs.

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3.5

ROBUST PERFORMANCE OF MULTIPLE TASKS BY AN AUTONOMOUS ROBOT

M. Beckerman D. L. Barnett*
 J. R. Einstein J. P. Jones
 P. F. Spelt C. R. Weisbin

(Abstract of paper presented at the Workshop on Integration of AI and Robotic Systems, Scottsdale, AZ, May 19, 1989)

There have been many successful mobile robot experiments, but very few papers have appeared that examine the range of applicability, or robustness, of a robot system. The purpose of this paper is to determine and quantify robustness of the Hermies-IIB experimental capabilities.

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

*Computing and Telecommunications Division.

3.6

WORLD MODELLING AND MULTI-SENSOR INTEGRATION FOR A MOBILE ROBOT

M. Beckerman L. A. Farkas*
 J. P. Jones R. C. Mann
 C. W. Glover

(Abstract of paper presented at the ANS Third Topical Meeting on Robotics and Remote Systems, Charleston, SC, March 13-16, 1989; Proc. Section 11-2, pp. 1-8 (1989))

In this paper we present a strategy for the reduction of systematic errors through the fusion of ultrasonic range and visual intensity information. This is done within a framework consisting of several world models, integration procedures, and sensor models which include appropriate sensor-specific signal and information processing algorithms. Among the world models are linked lists of geometric features extracted from the intensity images, and 2D Cartesian maps built from the sonar range data. Spatial reasoning was used in the fusion of ultrasonic data from multiple scans, and in the analysis of visual edge information following exchange of range and angular information across the sensor domains.

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

*Cornell University, Ithaca, NY.

3.7

TREATMENT OF SYSTEMATIC ERRORS IN THE PROCESSING OF WIDE ANGLE SONAR SENSOR DATA FOR ROBOTIC NAVIGATION

M. Beckerman E. M. Oblow

(Abstract of ORNL/TM-10763, April 1988; also *IEEE Trans. Robotics & Automation* (in press))

A methodology has been developed for the treatment of systematic errors which arise in the processing of sparse sensor data. We present a detailed application of this methodology to the construction from wide-angle sonar sensor data of navigation maps for use in autonomous robotic navigation. In the methodology we introduce a four-valued labelling scheme and a simple logic for label combination. The four labels, conflict, occupied, empty and unknown, are used to mark the cells of the navigation maps; the logic allows for the rapid updating of these maps as new information is acquired. The systematic errors are treated by relabelling conflicting pixel assignments. Most of the new labels are obtained from analyses of the characteristic patterns of conflict which arise during the information processing. The remaining labels are determined by imposing an elementary consistent-labelling condition.

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

3.8

AN APPROACH TO ELEMENTAL TASK LEARNING

P. F. R. Belmans*

(Abstract of paper to be presented at the International Society for Optical Engineers, Applications of Artificial Intelligence, Orlando, FL, April 16-20, 1990)

Today, great interest is granted to the development of learning abilities for machines. For our research carried out in the field of robotics, this means the capability by a robot of "understanding" and performing new tasks by observation of a human operator. This feature is useful in recovery procedures, when a mobile robot is unable to solve a given problem; the human operator takes over the control, e.g., performs necessary actions to reset the robot in a normal situation. If this recovery is properly analyzed and learned by the

robot, it would then be possible for it to solve similar situations in the future.

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

*On post-doctoral fellowship assignment at ORNL under NATO and CEA/UGRA/ROL sponsorship.

3.9

OBJECT RECOGNITION FOR THE HERMIES ROBOT

K. W. Bowyer*

(Abstract of ORNL/TM-10935, October 1988)

The HERMIES-IIB robot in the CESAR lab at ORNL is used in research related to vision, multi-sensor integration, coordinated arm movement, path planning, parallel algorithms, and learning. This report describes the development of a visual object recognition system for HERMIES. This system is implemented on an NCUBE system, an MIMD hypercube parallel computing system. In general, the input to the object recognition system will be an image containing one or more instances of the known different types of obstacles, and the output will be the location(s) of the obstacle(s) relative to the camera. Based on assumptions about the known geometry of the obstacles, the viewing conditions, the relevant range of viewing distances, and the image resolution needed, it is proposed that the obstacles can be recognized by the presence of roughly rectangular outlines in the image. The object recognition system uses Hough transforms to find rectangular outlines in the image and then uses a sequence of constraints to eliminate those outlines which could not be due to obstacles.

Research sponsored by U.S. DOE Office of Nuclear Energy, Technology Support Programs.

*University of South Florida, Tampa, FL.

3.10

A DEMONSTRATION OF AUTONOMOUS NAVIGATION AND MACHINE VISION USING THE HERMIES-IIB ROBOT

B. L. Burks D. L. Barnett*
J. P. Jones S. M. Killough†

(Abstract of paper presented at the Southeastern Regional Media Leadership Council Conference on Microcomputers and Artificial Intelligence in Communication Technologies, University of Tennessee at Chattanooga, Chattanooga, TN, October 29-31, 1987)

In earlier published work, the authors developed and demonstrated expert system control of an autonomous robot navigating in unknown environments and dealing with unexpected events such as moving obstacles. The limitations of this earlier work included insufficient on-board computing capability, restrictions on the sensor suite to only sonar transducers, and a geometrically specified goal location.

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 been ported to the on-board HERMIES-IIB computers thereby eliminating off-board computation. We describe 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 moving obstacles, picks up and moves small obstacles, searches for a control panel, and reads the meters found on the panel. The experiment will be expanded to include more complex on-board vision analysis and expert system control in dynamic environments as well as 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.

*Computing and Telecommunications Division.

†Instrumentation and Control Division.

3.11

ONGOING RESEARCH USING HERMIES — THE HOSTILE ENVIRONMENT ROBOTIC MACHINE INTELLIGENCE EXPERIMENT SERIES

B. L. Burks P. F. Spelt

(Abstract of paper presented at the Materials Handling FOCUS '88, Atlanta, GA, September 13-14, 1988; also DOE/ANL Training Course on the Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities, Idaho Falls, ID, August 29-September 1, 1988)

The Center for Engineering Systems Advanced Research (CESAR) was established in 1983 at Oak Ridge National Laboratory as a Department of Energy (DOE) Center of Excellence in the study of intelligent machines. The major emphasis of the research at CESAR is in basic research related to the operation of autonomous mobile robots in unstructured environments. The long-range goal of the research is to develop intelligent machine systems capable of replacing humans in potentially hazardous environment such as surveillance and maintenance functions in high radiation, deep underground or undersea areas. Currently research is underway and/or has been published in the areas of: real-time expert systems with dynamic replanning, modeling and control of light-weight, compliant, redundant manipulators mounted on a mobile vehicle; model-based scene understanding using multiple sensors, dynamic task allocation among heterogeneous resources, and machine learning.

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

3.12

AUTOMATIC LEARNING BY AUTONOMOUS MOBILE ROBOT

G. de Saussure P. F. Spelt
S. M. Killough* F. G. Pin
C. R. Weisbin

(Abstract of paper presented at the ANS Third Topical Meeting on Robotics and Remote Systems, Charleston, SC, March 13-16, 1989; Proc. Section 6-1, pp. 1-5 (1989))

This paper describes recent research in automatic learning by the autonomous mobile robot

HERMIES-IIB at the Center for Engineering Systems Advanced Research (CESAR). By acting on the environment and observing the consequences during a set of training examples, the robot learns a sequence of successful manipulations on a simulated control panel. The robot learns to classify panel configurations in order to deal with new configurations that are not part of the original training set.

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

* Fusion Energy Division.

3.13

NAVIGATION AND LEARNING EXPERIMENTS BY AN AUTONOMOUS ROBOT

G. de Saussure C. R. Weisbin
P. F. Spelt

(Abstract of paper presented at the Second International Symposium, Robotics and Manufacturing Research, Education, and Applications, Albuquerque, NM, November 16-18, 1988; Proc. pp. 935-948 (1989))

Developing an autonomous mobile robot capable of navigation, surveillance and manipulation in complex and dynamic environments is a key research activity at CESAR, Oak Ridge National Laboratory's Center for Engineering Systems Advanced Research. The latest series of completed experiments was performed using the autonomous mobile robot HERMIES-IIB (Hostile Environment Robotic Machine Intelligence Experiment Series II-B). The next section describes HERMIES-IIB and some of its major components required for autonomous operation in unstructured, dynamic environments. Section 3 outlines some ongoing research in autonomous navigation. Section 4 discusses our newest research in machine learning concepts. Section 5 describes a successful experiment in which the robot is placed in an arbitrary initial location without any prior specification of the content of its environment, successively discovers and navigates around stationary or moving obstacles, picks up and moves small obstacles, searches for a control panel, and performs a learned sequence of manipulations on the panel devices. The last section outlines some future directions of the program.

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

3.14

NON-LINEAR SURFACE FITTING OF LASER RANGE IMAGES USING A HYPERCUBE CONCURRENT COMPUTER

M. Finley*

(Abstract of ORNL/TM-11198, June 1989)

Segmentation and non-linear surface fitting with laser range images are attempted on a hypercube concurrent processor. Low-level software acquires range images onto the hypercube. A substantially modified existing range image edge detector works in the hypercube image analysis environment to accomplish segmentation. The Levenberg-Marquardt algorithm implements the non-linear least squares fitting of the surfaces.

Problems were found with each part of the approach. The edge detection algorithm is unnecessarily complex and yields an all too cluttered edge map. The fitting routine is limited by hardware in the number of surfaces that it can process. Finally, the fitting approach requires input estimates of the parameters which do not appear to be generalizable for any image, thus keeping the process from being totally automated. Other research in surface fitting on serial computers has yielded results which may be helpful additions to solve the problems of automation.

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

*Transylvania University, Lexington, KY.

3.15

NAVIGATION PLANNING USING QUADTREES

R. C. Fryxell*

(Abstract of ORNL/TM-10481, November 1987)

An algorithm is presented for planning a 2-D collision-free path for a mobile robot in an unstructured work environment. The algorithm assumes the existence of a pixel map of all or part of the environment, where each pixel is either on (implying blocked) or off (implying clear). The goal is to compute a "reasonable path" between two points in a minimal amount of time, and this is

achieved through a "compressed" representation of the pixel map using a modified quadtree data structure. The algorithm has been coded in the C programming language, and the results of tests made on "realistic" indoor environments are presented. A discussion on how the environmental maps were obtained from sonar range-finder data is also included.

Research sponsored by Albion College, Albion, MI, by Great Lakes Colleges Association, Ann Arbor, MI, and by U.S. DOE Office of Basic Energy Sciences.

*Albion College, Albion, MI.

3.16

THE MAN-ROBOT SYMBIOSIS PROJECT

W. R. Hamel* F. G. Pin

(Abstract of paper presented at the 1988 WATtec Conference, Knoxville, TN, February 16-19, 1988)

Remote operations which have been used to protect man from hazardous radioactive environments for nearly 40 years significantly reduce effective work proficiencies. In fact, the best master/slave manipulator systems in existence, while able to perform very complex tasks remotely, reduce work efficiency by factors of five to eight. The ultimate goal in remote operations is to perform necessary tasks at least as quickly as humans could do them with direct contact, and in some cases to hopefully be able to perform them even faster than manual operation allows. It is believed that the key to achieving such levels of performance is the integration of effective automation and intelligent control into the operation of advanced teleoperators. ORNL is pursuing this premise in a new research project called "Man-Robot Symbiosis." As the name implies, man-robot symbiosis is the next step beyond advanced telerobotics in which sensor, computers, and graphics will be integrated to accomplish cooperative man-machine control and intelligence in a dynamic and highly fluid way. The "symbiotic" system will facilitate cooperation to the mutual advantage of both the man and machine, and will ultimately facilitate the dynamic optimization of the division of work between the two.

Research sponsored by U.S. Department of Energy.

*Instrumentation and Controls Division.

3.17

SMEETING NETWORKS FOR REAL TIME COOPERATIVE PLANNING IN THE PRESENCE OF UNCERTAINTIES

**S. S. Iyengar* S. Gulati*
J. Barhen†**

(Abstract of paper presented at the Applications of Artificial Intelligence VI Conference, Orlando, FL, April 12-14, 1988)

The accelerated emphasis on research and development in massively parallel architectures, biological and neurocomputing, connectionist machines, etc., and their feasibility in near future, promises the AI community an opportunity for recovering from the "AI Trap" and the scepticism related to its applicability and deliverability for large scale applications. Given the gargantuan computational capabilities, an area where AI can be put to work extensively is the development of rule-based strategies for cooperative problem solving and planning in complex, spatially distributed systems and presence of uncertainties. This paper discusses the applicability and limitations of the existing AI paradigms in designing algorithms to do real time, onboard task planning for the multiple target tracking problem.

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

*Louisiana State University, Baton Rouge, LA.

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3.18

ASYNCHRONOUS PRODUCTION SYSTEMS FOR CONTROLLING AUTONOMOUS MOBILE ROBOTS

**S. S. Iyengar* C. R. Weisbin
F. G. Pin**

(Abstract of paper presented at the 8th International Congress of Cybernetics and Systems, Hunter College, New York, June 11-15, 1989)

Today, the robotics and automation community is being swept by broad, pervasive technological demands. The successful deployment of Intelligent Computing Systems for robotics and process control application requires an efficient integration of traditional expert system technologies

with real time response and control capabilities. To address such requirements, researchers at Oak Ridge National Lab and LSU have been working on a control architecture called Asynchronous Production System (APS), which is a rule-based inference engine capable of monitoring and processing asynchronous, real-time information. The primary motivation of the APS architecture is to provide a unique mechanism for designing rule-based expert systems capable of dynamic and rapid interaction with the environment. This paper elaborates on the implementation results of the APS in a multi-processor environment.

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

*Louisiana State University, Baton Rouge, LA.

3.19

THE U.S. DOE/NE UNIVERSITY PROGRAM IN ROBOTICS FOR ADVANCED REACTORS

R. C. Mann

(Abstract of paper presented at the 1988 WATtec Conference, Knoxville, TN, February 16-19, 1988)

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. DOE Office of Technology Support Programs.

3.20

THE DEVELOPMENT OF AN INTELLIGENT NUCLEAR MAINTENANCE ROBOT

R. C. Mann W. R. Hamel*
C. R. Weisbin

[Abstract of paper presented at the IEEE 1988 International Conference on Robotics and Automation, Philadelphia, PA, April 25-29, 1988; Proc. Vol. 1, pp. 621-623 (1988)]

The U.S. Department of Energy has provided support to four universities and the Oak Ridge National Laboratory (ORNL) in order to pursue research leading to the development and deployment of robotic system(s) for advanced nuclear power stations. This paper describes the scope of the program and the R&D effort contributed by ORNL.

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

*Instrumentation and Controls Division.

3.21

AN INTELLIGENT INTEGRATED SENSOR SYSTEM FOR THE ORNL MOBILE ROBOT

R. C. Mann J. P. Jones
M. Beckerman C. W. Glover
L. Farkas* J. Han
E. Wacholder J. R. Einstein

[Abstract of paper presented at the Third IEEE International Symposium on Intelligent Control, Arlington, VA, August 24-26, 1988; Proc. H. E. Stephanou, A. Meystel, and J. Y. S. Luh, Eds., pp. 170-173 (1989)]

The mobile robot prototypes developed at the ORNL Center for Engineering Systems Advanced Research (CESAR) are equipped with sonar sensors and CCD cameras that are used to support autonomous navigation and simple inspection tasks in an *a priori* unknown and unstructured dynamic environment. A laser range camera is being added to the sensor suite of HERMIES III, a mobile robot that is currently being built. This paper summarizes work directed at extracting information from data collected with these sensors and integrating it, in order to produce reliable descriptions of the robot's environment. Specifically, the paper describes the integration of two-dimensional

vision and sonar range information. All operations are carried out onboard the mobile robot using a 16-processor hypercube computer.

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

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3.22

U.S. DEPARTMENT OF ENERGY NUCLEAR ENERGY UNIVERSITY PROGRAM IN ROBOTICS FOR ADVANCED REACTORS

R. C. Mann R. C. Gonzalez*
D. Tesar† J. S. Tulenko‡
D. K. Wehe§

(Abstract of DOE/OR-884/R1, July 1988)

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 advanced robotic systems 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 economically performing surveillance, maintenance, and repair tasks in nuclear facilities and other hazardous environments.

This program features a unique teaming arrangement among the Universities of Florida, Michigan, Tennessee, Texas, and the Oak Ridge National Laboratory, and their industrial partners, Combustion engineering, Odetics, Gulf State Utilities, Florida Power and Light Company, Remotec, and Telerobotics International. Each of the universities and ORNL have ongoing activities and corresponding facilities in areas of R&D related to robotics. This program is designed to take full advantage of a balance of these existing resources at the participating institutions.

Research sponsored by U.S. DOE Office of Technology Support Programs.

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3.23

RESEARCH IN MOBILE ROBOTICS AT ORNL/CESAR

R. C. Mann C. R. Weisbin
F. G. Pin

[Abstract of paper presented at the 1989 IEEE International Conference on Systems Engineering, Dayton, OH, August 24-26, 1989; Proc. pp. 367-371 (1989)]

This paper reviews ongoing and planned research with mobile autonomous robots at the Oak Ridge National Laboratory (ORNL), Center for Engineering Systems Advanced Research (CESAR). Specifically we report on results obtained with the robot HERMIES-IIB in navigation, intelligent sensing, learning, and on-board parallel computing in support of these functions. We briefly summarize an experiment with HERMIES-IIB that demonstrates the capability of smooth transitions between robot autonomy and teleoperation. This experiment results from collaboration among teams at the Universities of Florida, Michigan, Tennessee, and Texas; and ORNL in a program targeted at robotics for advanced nuclear power stations. We conclude by summarizing ongoing R&D with our new mobile robot HERMIES-III which is equipped with a seven degree-of-freedom research manipulator arm.

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

3.24

ADAPTIVE OPTIMAL CONTROL OF UNCERTAIN NONLINEAR SYSTEMS: ON-LINE MICROPROCESSOR-BASED ALGORITHM TO CONTROL MECHANICAL MANIPULATORS

C. March-Leuba* R. B. Perez

(Abstract of ORNL/TM-10764, May 1988)

This report presents an adaptive optimal control algorithm for uncertain nonlinear systems. A variational technique based on Pontryagin's Maximum Principle is used to track the system's unknown terms and to calculate the optimal control. The reformulation of the variational technique as an Initial Value Problem allows this microprocessor-based algorithm to perform on-line model-updating and control. To validate the algo-

rithm, a system representing a two-link mechanical manipulator is simulated. In the control model, the coupling and friction terms are unknown. The robot's task is to follow a prescribed trajectory and to pick up an unknown mass.

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

*University of Tennessee, Knoxville, TN.

3.25

OPTIMAL CONTROL OF UNCERTAIN NONLINEAR SYSTEMS: AN APPLICATION TO A TWO-LINK ROBOTIC ARM

C. March-Leuba* R. B. Perez

(Abstract of paper presented at the 27th IEEE Conference on Decision and Control, Austin, TX, December 7-9, 1988)

This paper presents an adaptive optimal control algorithm for uncertain nonlinear systems. A variational technique based on Pontryagin's Maximum Principle is used to track the system's unknown terms and to calculate the optimal control. The reformulation of the variational technique as an initial value problem allows this microprocessor-based algorithm to perform as a closed-loop controller by updating the model and controlling the system on-line. To validate the algorithm a system representing a two-link mechanical manipulator is simulated. In the control model, the coupling and friction terms are unknown. The robot's task is to follow a prescribed trajectory and to pick up an unknown mass.

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

*Instrumentation and Controls Division.

3.26

A PROBABILISTIC-PROPOSITIONAL FRAMEWORK FOR THE O-THEORY INTERSECTION RULE

E. M. Oblow

[Abstract of *J. General Systems* 13, 187 (1987)]

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 notions which are the distinguishing features of this operator's role in the theory.

The OT intersection rule has as its basis Dempster's rule of combination which ties it closely to Dempster-Shafer theory. In this paper the OT rule will be shown to be based more fundamentally on classical probability theory. To demonstrate this, possibility sets are interpreted in a propositional framework and mass assignments are converted to the probabilistic form originally proposed by Dempster. These changes are used to show that the OT intersection rule can be derived from first principles in a probability theory of propositions. Since this derivation does not require conditional probabilities, it can be used as alternative to Bayes' theorem for combining conjunctive information consistently. Dempster's rule will be shown to be a special case of the OT intersection rule. It too will be derived using probability theory.

The formal connection between mass and probability presented originally by Dempster and used here in a propositional framework, makes distinctions between DST and probability theory less consequential. DST is still seen to be a generalization of the concept of probability, but it is also seen to fit within a probabilistic-propositional framework.

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

3.27

FOUNDATIONS OF O-THEORY: MEASUREMENTS AND RELATION TO FUZZY SET THEORY

E. M. Oblow

[Abstract of *Int. J. General Systems* 14, 357-378 (1983)]

A measurement framework for O-theory, an algebra of random sets, 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. This framework allows a connection to be made between this random set algebra and the possibilistic form of fuzzy set theory. Instances in which these two different representations of the same experimental data are equivalent are ex-

plored. The relationships between some basic operators in both theories are then discussed, along with their connector 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.

3.28

SUPERTRACKS, SUPERTRACK FUNCTIONS AND CHAOS IN THE QUADRATIC MAP

E. M. Oblow

[Abstract of *Phys. Letters A* 128(8), 406 (1988)]

Chaotic behavior for the quadratic map is conjectured to be a bounding phenomenon based on state-space trajectories starting from the maximum in the map. These trajectories, called *supertracks*, have no sensitivity to initial conditions. The chaotic regime is found to be characterized recursively by these trajectories as functions of the map parameter.

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

3.29

MAN-ROBOT SYMBIOSIS: A FRAMEWORK FOR COOPERATIVE INTELLIGENCE AND CONTROL

L. E. Parker F. G. Pin

[Abstract of paper presented at the SPIE Conference on Sensor Fusion: Spatial Reasoning and Scene Interpretation, Cambridge, MA, November 6-11, 1988; Proc. Vol. 1006, pp. 94-103 (1988)]

The man-robot symbiosis concept has the fundamental objective of bridging the gap between fully human-controlled and fully autonomous systems to achieve true man-robot cooperative control and intelligence. Such a system would allow improved speed, accuracy, and efficiency of task execution, while retaining the man in the loop for innovative reasoning and decision-making. The symbiont would have capabilities for supervised and unsupervised learning, allowing an in-

crease of expertise in a wide task domain. This paper describes a robotic system architecture facilitating the symbiotic integration of teleoperative and automated modes of task execution. The architecture reflects a unique blend of many disciplines of artificial intelligence into a working system, including job or mission planning, dynamic task allocation, man-robot communication, automated monitoring, and machine learning. These disciplines are embodied in five major components of the symbiotic framework: the Job Planner, the Dynamic task Allocator, the Presenter/Interpreter, the Automated Monitor, and the Learning System.

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

3.30

1988 WORKSHOP ON HUMAN-MACHINE SYMBIOTIC SYSTEMS

Editors:

L. E. Parker C. R. Weisbin

(Abstract of proceedings of the 1988 Workshop on Human-Machine Symbiotic Systems, Oak Ridge, TN, December 5-6, 1988)

This report presents the proceedings of the 1988 Workshop on Human-Machine Symbiotic Systems. Held December 5-6, 1988 in Oak Ridge, Tennessee, the workshop served as a forum for the discussion of several critical issues in human-machine symbiosis: human-machine communication, autonomous task planning and execution monitoring for heterogeneous agents, dynamic task allocation, human-machine system architecture, and machine learning via experience and human observation. The presentation of overview papers by invited keynote speakers provided a background for the breakout session discussions in these five areas. The full papers furnished by the speakers are included in the proceedings, along with written summaries of the group discussions that report session conclusions and recommendations for future work.

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

3.31

REVIEW OF THE 1988 WORKSHOP ON HUMAN-MACHINE SYMBIOTIC SYSTEMS

L. E. Parker C. R. Weisbin

(Abstract of paper presented at the Workshop on Integration of AI and Robotic Systems, Scottsdale, AZ, May 19, 1989)

This report presents a review of the 1988 Workshop on Human-Machine Symbiotic Systems. Held December 5-6, 1988 in Oak Ridge, Tennessee, the workshop served as a forum for the discussion of several critical issues in human-machine symbiosis: human-machine communication, autonomous task planning and execution monitoring for heterogeneous agents, dynamic task allocation, human-machine system architecture, and machine learning via experience and human observation. The presentation of overview papers by invited keynote speakers provided a background for the breakout session discussions in these five areas. A summary of the conclusions and recommendations for the future work resulting from the workshop is reported.

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

3.32

AUTONOMOUS MOBILE ROBOT RESEARCH USING THE HERMIES-III ROBOT

F. G. Pin M. Beckerman
P. F. Spelt J. T. Robinson*
C. R. Weisbin

(Abstract of paper presented at the '89 IROS International Conference on Intelligent Robot and Systems, "The Autonomous Robot and Its Application," Tsukuba, Japan, September 3-7, 1989)

This paper reports on the status and future directions in the research, development and experimental validation of intelligent control techniques for autonomous mobile robots using the HERMIES-III robot at the Center for Engineering Systems Advanced Research (CESAR) at Oak Ridge National Laboratory (ORNL). HERMIES-III is the fourth robot in a series of increasingly more sophisticated and capable experimental

test beds developed at CESAR. HERMIES-III is comprised of a battery powered, onmi-directional wheeled platform with a seven degree-of-freedom manipulator arm, video camera, sonar range sensors, laser imaging scanner and a dual computer system containing up to 128 NCUBE nodes in hypercube configuration. All electronics, sensors, computers, and communication equipment required for autonomous operation of HERMIES-III are located on board along with sufficient battery power for three to four hours of operation. The paper first provides a more detailed description of the HERMIES-III characteristics, focussing on the new areas of research and demonstration now possible at CESAR with this new test-bed. The initial experimental program is then described with emphasis placed on autonomous performance of human-scale tasks (e.g., valve manipulation, use of tools), integration of a dexterous manipulator and platform motion in geometrically complex environments, and effective use of multiple cooperating robots (HERMIES-IIB and HERMIES-III). The paper concludes with a discussion of the integration problems and safety considerations necessarily arising from the set-up of an experimental program involving human-scale, multi-autonomous mobile robots performance.

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

* Instrumentation and Controls Division.

3.33

RECENT CESAR RESEARCH ACTIVITIES IN SENSOR BASED REASONING FOR AUTONOMOUS MACHINES

F. G. Pin G. de Saussure
P. F. Spelt S. M. Killough*
C. R. Weisbin

[Abstract of paper presented at the IEEE International Workshop on Intelligent Robots and Systems, Tokyo, Japan, October 31-November 2, 1988; Proc. 417-421 (1988)]

This paper describes recent research activities at the Center for Engineering Systems Advanced Research (CESAR) in the area of sensor based reasoning, with emphasis being given to their application and implementation on our HERMIES-IIB autonomous mobile vehicle. These activities, including navigation and exploration in *a-priori* unknown and dynamic environments, goal recogni-

tion, vision-guided manipulation and sensor-driven machine learning are discussed within the framework of a scenario in which an autonomous robot is asked to navigate through an unknown dynamic environment, explore, find and dock at the panel, read and understand the status of the panel's meters and dials, learn the functioning of a process control panel, and successfully manipulate the control devices of the panel to solve a maintenance emergency problem. A demonstration of the successful implementation of the algorithms on our HERMIES-IIB autonomous robot for resolution of this scenario is presented. Conclusions are drawn concerning the applicability of the methodologies to more general classes of problems and implications for future work on sensor-driven reasoning for autonomous robots are discussed.

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

* Instrumentations and Controls Division.

3.34

DESIGN OF AN OBSTACLE AVOIDANCE SYSTEM FOR AIMS

D. B. Reister M. W. Noakes*

[Abstract of paper presented at the SPIE Conference on Sensor Fusion: Spatial Reasoning and Scene Interpretation, Cambridge MA, November 6-11, 1988; Proc. Vol. 1006, pp. 124-131 (1988)]

The Advanced Integrated Maintenance System (AIMS) is a remote maintenance system that uses a dual-arm teleoperator to control the Advanced Servomanipulator (ASM). Although, the ASM was designed for nuclear fuel reprocessing, it can provide a testbed for space telerobotics (space servicing and assembly). The objective of this project is to design and implement a generalized capability for automatic path-planning and obstacle avoidance during motion of the manipulator transporter (overhead crane and main manipulator shaft) from one work location in the hotcell to another. The work is to be accomplished in two phases. In the first phase, the transporter will move in a known world. In the second phase, sensor data will be used to update and verify the world model. This paper describes the development of a system for phase one and describes the plans for phase two.

Before the design of the phase two system, an extensive program of experiments will be conducted using three types of sensors: laser rangefinders, phased array sonar, and television cameras.

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

*Instrumentation and Controls Division.

3.35

LEARNING BY AN AUTONOMOUS ROBOT AT A PROCESS CONTROL PANEL

P. F. Spelt G. de Saussure
E. Lyness* F. G. Pin
C. R. Weisbin

[Abstract of *IEEE Expert* (in press)]

The Center for Engineering Systems Advanced Research (CESAR) was founded at Oak Ridge National Laboratory (ORNL) by the Department of Energy's Office of Energy Research/Division of Engineering and Geoscience (DOE-OER/DEG) to conduct basic research in the area of intelligent machines. Within this framework, CESAR has undertaken several research activities in the field of machine learning. In this paper, we describe our approach to a class of machine learning which involves autonomous concept formation using feedback from trial-and-error learning. Our formulation is being experimentally validated using an autonomous robot, learning tasks of control panel monitoring and manipulation in effective process control. The CLIPS Expert System which resides in a hypercube computer aboard the robot, and the knowledge base used by the robot in the learning process are described in detail. Benchmark testing of the learning process on a robot/control panel emulator system consisting of two interacting computers is presented, along with results of sample problems illustrating machine learning and robot performance improvement. Conclusions are drawn concerning the applicability of the system to a more general class of learning problems, and implications for future work on machine learning for autonomous robots are discussed.

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

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3.36

PATH-PLANNING IN A KNOWN ENVIRONMENT WITH UNEXPECTED OBSTACLES: POTENTIAL APPLICATION TO AN AUTOMATIC ALARM TESTING ROBOT

N. Sreenath

(Abstract of ORNL/TM-10726, May 1988)

The feasibility of using an expanded version of a path planning algorithm in the development of an Automatic Alarm Testing Robot (AATR) was investigated. Use of an AATR for security tasks implies the requirement that communication exists between the robot and the security systems or personnel except in the event of a site emergency or mechanical failure aboard the robot. Furthermore, the execution of the actual alarm testing needs to be carried out in narrow, pre-defined time windows. Thus the path planning algorithm for such a robot should be capable of not only taking the robot from one point to another in a known environment with unexpected (*a priori* unknown) obstacles in real time, but also time-synchronization with the security systems. Here we propose such an algorithm which uses a breadth-first search technique and discuss its implementation onboard the HERMES IIB robot. A demonstration of the algorithm in a hard real-time environment is presented and some future desirable enhancements of the algorithm are discussed.

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

3.37

PARALLELISM IN PRODUCTION SYSTEMS

A. Sabharwal* S. S. Iyengar*
G. de Saussure C. R. Weisbin

(Abstract of paper presented at the Applications of Artificial Intelligence VI Conference, Orlando, FL, April 12-14, 1988)

Production systems have found considerable popularity in the areas of artificial intelligence and expert system development. Part of their popularity stems from their proven use as convenient tools for knowledge representation and logic program-

ming. Unfortunately, their obvious advantages are accompanied by a series drawback — being computationally very expensive, production systems tend to be inherently slow.

In this paper, an n -ary tree architecture is proposed which effectively combines the production-level and condition-level parallelism inherent in the match process.

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

*Louisiana State University, Baton Rouge, LA.

3.38

ASYNCHRONOUS PRODUCTION SYSTEMS

A. Sabharwal* S. S. Iyengar*
C. R. Weisbin F. G. Pin

[Abstract of *Knowledge-Based Systems* 2(2), 117-127 (1989)]

Intelligent computing systems for aerospace, robotics and process control applications require an integration of traditional expert system technologies with real-time response and control capabilities. To address such requirements, the Asynchronous Production System (APS) is presented, which is a rule-based inference engine capable of monitoring and processing asynchronous, real-time information. The primary motivation of the proposed APS is to provide a unique and convenient mechanism for designing rule-based expert systems capable of dynamic and rapid interaction with their environments. This paper elaborates on the architectural and operational characteristics of the APS and addresses issues pertinent to implementation of the APS in a multi-processor environment.

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

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3.39

ASYNCHRONOUS PRODUCTION SYSTEMS FOR REAL-TIME EXPERT SYSTEMS

A. Sabharwal* S. S. Iyengar*
C. R. Weisbin F. G. Pin

[Abstract of paper presented at Avignon '88 Eighth International Workshop on Expert Systems and Their Applications, Nanterre, France, May 30-June 3, 1988; Proc. pp 113-146 (1988)]

Intelligent Computing Systems for Autonomous Mobile Robots and Process Control applications require an integration of traditional expert system technologies with real-time response and control capabilities. To address such requirements, we propose an *Asynchronous Production System* (APS), which is a rule-based inference engine capable of monitoring and processing asynchronous, real-time information. The primary motivation of the proposed APS is to provide a unique and convenient mechanism for development of rule-based expert systems capable of dynamic and rapid interaction with their environments. This paper elaborates on the architectural, operational and implementational ramifications of Asynchronous Production Systems. To facilitate its description, an example of an APS-based distributed expert system is presented to handle the task of autonomous navigation in the presence of unexpected, moving obstacles in a mobile robot.

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

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3.40

A TWO-PC SIMULATION FOR DEVELOPMENT AND TRAINING OF A LEARNING EXPERT SYSTEM IN AN AUTONOMOUS MOBILE ROBOT

P. F. Spelt E. Lyness*
G. de Saussure

[Abstract of *Simulation Journal* (in press)]

The Center for Engineering Systems Advanced Research (CESAR) at Oak Ridge National Laboratory conducts basic research in the area of intelligent machines. Recently at CESAR

a learning expert system was created to operate on board an autonomous robot in real time at a process control panel. In this paper we present the development and use of a two-computer concurrent simulation system used to create, evaluate and train this learning system. The simulation system uses graphics to display the current status of the process being simulated, and the same program which does the simulating also drives the actual control panel process. We discuss the value of using a computerized simulator to train a learning computer.

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

*Iowa State University, Ames, IA.

3.41

DYNAMICS FOR SPACE BASED ROBOTIC MANIPULATION

N. Sreenath P. S. Krishnaprasad*

[Abstract of paper presented at the 26th IEEE Conference on Decision and Control, Los Angeles, CA, December 9-11, 1987; Proc. Vol. II, p. 1417 (1987)]

In this paper, we present new results on the Hamiltonian structures of planar multibody systems. The models we obtain are reduced models accounting for the symmetry group of rigid motions in the plane. We give some new controllability and stabilizability theorems for articulating such multibody systems. The models of this paper provide a natural framework for questions of inverse kinematics arising in space based robotic manipulation. We find some very interesting applications of *holonomy* in this context.

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

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3.42

INTELLIGENT ROBOTICS AND REMOTE SYSTEMS FOR THE NUCLEAR INDUSTRY

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W. R. Martin* R. C. Mann
W. R. Hamel† J. S. Tulenko‡

[Abstract of *Nuclear Engineering and Design* 113, 259-267 (1989)]

The nuclear industry has a recognized need for intelligent, multitask robots to carry out tasks in harsh environment. From 1986 to the present, the number of robotic systems available or under development for use in the nuclear industry has more than doubled. Presently, artificial intelligence (AI) plays a relatively small role in existing robots used in the nuclear industry. Indeed, the lack of intelligence has been labeled the "Achilles heel" of all current robotic technology. However, larger-scale efforts are underway to make the multitask robot more sensitive to its environment, more capable to move and perform useful work, and more fully autonomous via the use of AI. In this paper, we review the terminology, the history, and the factors which are motivating the development of robotics and remote systems; discuss the applications related to the nuclear industry; and, finally, examine the state of the art of the technologies being applied to introduce more autonomous capabilities. Much of this latter work can be classified as within the artificial intelligence framework.

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

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3.43

RESEARCH IN AUTONOMOUS ROBOTICS AT ORNL USING HERMIES-III

C. R. Weisbin B. L. Burks
J. R. Einstein R. R. Feezell*
W. W. Manges* D. H. Thompson*

(Abstract of paper presented at the 1989 ASME Pressure Vessels and Piping Conference, Honolulu, HI, July 23-27, 1989)

HERMIES-III is an autonomous robot comprised of a seven degree-of-freedom (DOF) manipulator designed for human scale tasks, a laser range finder, a sonar array, an omni-directional wheel-driven chassis, multiple cameras, and a dual computer system containing a 16-node hypercube expandable to 128 nodes. The current experimental program involves performance of human-scale tasks (e.g., valve manipulation, use of tools), integration of a dexterous manipulator and platform motion in geometrically complex environments, and effective use of multiple cooperating robots (HERMIES-IIB and HERMIES-III). The environment in which the robots operate has been designed to include multiple valves, pipes, meters, obstacles on the floor, valves occluded from view, and multiple paths of differing navigation complexity. The ongoing research program supports the development of autonomous capability for HERMIES-IIB and III to perform complex navigation and manipulation under time constraints while dealing with imprecise sensory information.

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

*Instrumentation and Controls Division.

3.44

HERMIES-III: A STEP TOWARD AUTONOMOUS MOBILITY, MANIPULATION AND PERCEPTION

C. R. Weisbin B. L. Burks
J. R. Einstein R. R. Feezell*
W. W. Manges* D. H. Thompson*

(Abstract of paper presented at the NASA Conference on Space Telerobotics, Pasadena, CA, January 31-February 2, 1989)

HERMIES-III is an autonomous robot comprised of a seven degree-of-freedom (DOF) manipulator designed for human scale tasks, a laser range finder, a sonar array, an omni-directional wheel-driven chassis, multiple cameras, and a dual computer system containing a 16-node hypercube expandable to 128 nodes. The current experimental program involves performance of human-scale tasks (e.g., valve manipulation, use of tools), integration of a dexterous manipulator and platform motion in geometrically complex environments, and effective use of multiple cooperating robots (HERMIES-IIB and HERMIES-III). The environment in which the robots operate has been designed to include multiple valves, pipes, meters, obstacles on the floor, valves occluded from view, and multiple paths of differing navigation complexity. The ongoing research program supports the development of autonomous capability for HERMIES-IIB and III to perform complex navigation and manipulation under time constraints, while dealing with imprecise sensory information.

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

*Instrumentation and Controls Division.

3.45

AUTONOMOUS MOBILE ROBOT NAVIGATION AND LEARNING

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F. G. Pin

[Abstract of *Computer Magazine* 22(6), 29-35 (June 1989)]

This paper reviews ongoing and planned research for mobile, autonomous robots including aspects of navigation, exploration, recognition and learning, as performed at the Oak Ridge National Laboratory (ORNL), Center for Engineering Systems Advanced Research (CESAR). We begin with a discussion of the HERMIES-IIB robot, a self-powered, wheel-driven platform used primarily for navigation and surveillance research. The vehicle contains an on-board, 16-node NCUBE hypercube parallel processor interfaced to effectors and sensors through a Motorola 68020 processor. HERMIES-IIB uses a phased sonar array and multiple camera to sense its environment.

The software for HERMIES-IIB control is next described including detailed discussion of its expert system brain, constructed to handle numerical and symbolic information processing dealing with real-time decision making (including consideration of unexpected events).

The capability for HERMIES-IIB to perform intelligently depends vitally on its capability for perception. We review completed CESAR research pertaining to on-board vision processing, combinatorial geometry representation of range information, and algorithms to resolve conflict among seemingly disparate sonar data. Techniques to systematically integrate information from multiple sensors in a consistent way are described. Our efforts to incorporate the capability for HERMIES-IIB to improve its performance through autonomous machine learning are described, and experimental results are presented. A complete experiment is then described, and the results presented, which illustrate HERMIES-IIB capability for dynamic replanning.

The paper concludes with a discussion of HERMIES-III, and the associated research program. HERMIES-III is comprised of a seven degree-of-freedom manipulator designed for human scale tasks, a laser range finder, an omnidirectional, wheel-driven chassis, in addition to multiple cameras, sonar arrays, and a 16-node hy-

percube expandable to 64 nodes. The current experimental program involves performance of actual human-scale tasks (e.g., valve manipulation, use of tools), integration of dexterous manipulators and platform motion in geometrically complex environments, and effective use of multiple co-operating robots (HERMIES-IIB and HERMIES-III). The environment in which the robots operate include multiple valves, pipes, meters, obstacles on the floor, absence of an accurate world model, valves occluded from view, multiple paths of differing complexity, and tasks subject to fixed time constraints. The research described supports the development of autonomous capability for HERMIES IIB and III to perform complex navigation and manipulation in time constrained, emergency environments while dealing with imprecise information.

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

*Heer Associates, LaCanada, CA.

3.46

THE ROBOTICS AND INTELLIGENT SYSTEMS PROGRAM AT ORNL

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D. P. Kuban† S. A. Meacham‡
F. G. Pin

[Abstract of *Robotics* 7(2), 101-111 (April 1989)]

This paper describes the Robotics and Intelligent Systems Program (RISP) at the Oak Ridge National Laboratory (ORNL). RISP is a focal point at ORNL for studies in robotics, teleoperations, and related aspects of intelligent machines, such as artificial intelligence, neural network, and parallel computing. 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; to optimize cooperation of humans and machines; and to cope effectively with emergency situations where fast response is essential.

Research sponsored by U.S. DOE, U.S. Department of Defense, and National Aeronautical and Space Administration.

*Instrumentation and Controls Division.

†ORNL Engineering (R&D) Division.

‡Fuel Recycle Division.

CONCURRENT COMPUTING

3.47

COMPUTING THE HOUGH TRANSFORM ON AN MIMD HYPERCUBE

K. W. Bowyer* J. P. Jones
C. H. Lake*

(Abstract of paper presented at the 6th Scandinavian Image Analysis Conference, Oulu, Finland, June 19-22, 1989)

The computational expense of Hough transforms has prompted researchers to investigate the feasibility of parallel implementations. Most such work to date has dealt with special-purpose architectures or with implementations for SIMD machines such as the MPP or GAPP. This report considers the problem of efficiently implementing Hough transforms on an MIMD hypercube architecture. Beginning with a general analysis of how the data structures might be partitioned to allow a parallel computation, we formulate algorithm and data structure partitioning strategies appropriate to the architecture and then discuss modifications to optimize the performance for a particular hypercube system (the NCUBE). We also present the results of implementing and benchmarking Hough transforms on a 64-processor NCUBE.

Research sponsored by the Air Force Office of Scientific Research, National Science Foundation, U.S. DOE Office of Nuclear Energy, the Office of Technology Support Programs, and the Office of Basic Energy Science.

*University of South Florida, Tampa FL.

3.48

A CONCURRENT APPROACH TO MODEL-BASED MOTION DETECTION

H. I. Christensen*

(Abstract of ORNL/TM-11051, January 1989)

In robot-vision it is important to be able to acquire and describe dynamically changing scenes. A token based method for real-time motion detection is described here. This method uses a prediction-verification scheme to cope with ambiguous motion patterns. To improve performance it is investigated how the application may be implemented on a concurrent architecture

like a hypercube. An implementation based on the SPMD approach is presented together with some experimental results. The results demonstrate the systems ability to handle ambiguous situations. Timing results indicate the system has a potential for tracking of less than 10 objects or more than 40 objects, while the advantage of using a concurrent architecture for 10-40 objects is very small.

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

*Aalborg University, Aalborg, Denmark.

3.49

CONCURRENT SPATIO-TEMPORAL IMAGE ANALYSIS

H. I. Christensen*

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989)

A new method for motion detection is introduced. The method is based on extraction of global/long-term motion descriptors from low-resolution images while detailed/short term motion descriptors are extracted from higher resolution images. This approach can be characterized as a method of least effort, i.e., as much information as possible is extracted from low resolution images.

An experimental implementation based on the method of least effort is reported for a hypercube architecture (NCUBE Corp., Beaverton, OR). Results indicating the generality of the approach are also presented. The implementation allows discussion and measurement of scaling properties for the method and a comparison to performance on a pyramid architecture.

Research sponsored by U.S. DOE Office of Nuclear Energy and by Danish Technical Research Council.

*Aalborg University, Aalborg, Denmark.

3.50

CONCURRENT MULTI-RESOLUTION IMAGE ANALYSIS

H. I. Christensen* J. P. Jones

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989)

Analysis at multiple resolutions can simplify many image analysis problems. In such methods, a coarse-to-fine search strategy replaces an exhaustive search for features within a single resolution image. Coarse resolution images are used for extraction of global information in a hypothesis formation process. Analysis of finer resolution images are subsequently used for hypothesis verification or rejection. The multiresolution hierarchy of images forms a data structure known as a pyramid, and a tightly coupled synchronous multiprocessor architecture (the pyramid machines) has been developed for the analysis of such structures.

In this paper, methods for multiresolution image analysis using the more general hypercube architecture are discussed, and a particular implementation is presented. The implementation has been designed to process pyramids of images of almost arbitrary size composed of pixels of arbitrary storage class on hypercubes of arbitrary dimension. An efficient dereferencing strategy permits the construction of a broad class of efficient algorithms for traversing the pyramid. An experimental implementation on a hypercube multiprocessor (NCUBE Corp., Beaverton, OR) is presented. The implementation demonstrates almost linear scaling properties. We discuss these properties and compare performance to pyramid architectures.

Research sponsored by U.S. DOE Office of Nuclear Energy Technology Support Programs and by Danish Technical Research Council.

*Aalborg University, Aalborg, Denmark.

3.51

A TOOL TO AID IN MAPPING COMPUTATIONAL TASKS TO A HYPERCUBE

J. R. Einstein C. W. Glover
M. Dickens*

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989)

We describe a tool to aid in static scheduling of precedence-constrained tasks on nodes of a hypercube computer. The tool is useful where the sequential program is suitable for large-grained decomposition, i.e., where message-passing times are negligibly small compared to task execution times. The tool is also useful for small sets of tasks, or for quasi-periodic sets of tasks, even where message-passing times are not negligible. Quasi-periodic sets of tasks arise when the computation is dominated by loops over a group of tasks which are the same or nearly the same for each iteration of the loop - for example, programs for the dynamics and kinematics of robotic manipulators.

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

*Massachusetts Institute of Technology, Cambridge, MA.

3.52

DESIGN AND IMPLEMENTATION OF A MULTI-SENSOR FUSION ALGORITHM ON A HYPERCUBE COMPUTER ARCHITECTURE

C. W. Glover

(Abstract of paper to be presented at the Sensor Fusion II: Human and Machine Strategies SPIE's Advances in Intelligent Robotics, Philadelphia, PA, November 5-10, 1989)

A multi-sensor integration (MSI) algorithm written for sequential single processor computer architecture has been transformed into a concurrent algorithm and implemented in parallel on a multi-processor hypercube computer architecture. This paper will present the philosophy and methodologies used in the decomposition of the sequential MSI algorithm, and its transformation into a parallel MSI algorithm. The parallel MSI algorithm was implemented on a NCUBETM hypercube computer. The performance of the parallel

MSI algorithm has been measured and compared against its sequential counterpart by running test case scenarios through a simulation program. The simulation program allows the user to define the trajectories of all players in the scenario, and to pick the sensor suites of the players and their operating characteristics. For, example, an air-to-air engagement scenario was used as one of the test cases. In this scenario, two friend aircrafts were being attacked by six foe aircrafts in a pincer maneuver. Both the friend and foe aircrafts launch missiles at several different time points in the engagement. The sensor suites on each aircraft are dual mode RADAR, dual modeIRST, and ESM sensors. The modes of the sensors are switched as needed throughout the scenario. The RADAR sensor is used only intermittently, thus most of the MSI information is obtained from passive sensing. The maneuvers in this scenario caused aircraft and missile to constantly fly in and out of sensors field-of-view (FOV). This resulted in the MSI algorithm to constantly reacquire, initiate, and delete new tracks as it tracked all objects in the scenario. The objective was to determine performance of the parallel MSI algorithm in such a complex environment, and to determine how many multi-processors (nodes) of the hypercube could be effectively used by an aircraft in such an environment. For the scenario just discussed, a 4-node hypercube was found to be the optimal size and a factor two in speedup was obtained. This paper will also discuss the design of a completely parallel MSI algorithm. targets.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratory and U.S. DOE Office of Basic Energy Sciences.

3.53

MULTI-SENSOR INTEGRATION ON THE NCUBETM HYPERCUBE COMPUTER

C. W. Glover

[Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988; Proc. Vol. II, pp. 1236-1246, Geoffrey Fox. Ed. (1988)]

This paper presents the quantitative performance results obtained from converting a large sequential Multi-Sensor Integration (MSI) program into a concurrent form and executing the program on an NCUBE hypercube computer for several test

case scenarios. Each sensor track was assigned to a different node of the hypercube where computationally intensive calculations were performed. A 4-node hypercube was found to be the optimal size for the test case scenario discussed here, where speed-up factors of 1.5 to 1.7 were obtained. A completely concurrent MSI algorithm is also presented.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

3.54

CONCURRENCY IN MOBILE ROBOTICS AT ORNL

J. P. Jones

(Abstract of oral presentation presented at the International Workshop on Concurrent Computer Vision, Aalborg, Denmark, January 25-27, 1989)

The Center for Engineering Systems Advanced Research (CESAR) was established in 1983 by the U.S. Department of Energy at the Oak Ridge National Laboratory to perform basic research and development in autonomous mobile and manipulative robots for energy-related applications. Early in the program it was recognized that autonomy implied the solution, in real-time, of a variety of complex problems in mathematical modeling, sensor data processing, and multi-sensor integration. This realization led to the study of concurrent computing, focusing specifically on issues related to hypercube concurrent multicomputers.

In this talk we present the hardware architecture of HERMIES-IIB, our first mobile robot with an on-board concurrent computer, and its successor, presently under development, HERMIES-III. We discuss the organization of tasks in the present system and present some options for the future.

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

3.55

CONCURRENT COMPUTER VISION ON A HYPERCUBE MULTICOMPUTER

J. P. Jones

(Abstract of oral presentation presented at the International Workshop on Concurrent Computer Vision, Aalborg, Denmark, January 25-27, 1989)

This decade has witnessed the development and commercialization of the first generation of practical general-purpose multicomputers (tightly-coupled distributed-memory concurrent multiprocessors). One of the most popular commercial-grade architectures is the hypercube-connected multicomputer, which has been successfully used in a wide variety of applications from physics to artificial intelligence.

Here we present a brief review of the properties of hypercube multicomputers, with specific reference to the NCUBE, Inc. (Beaverton, OR) machine and a discussion of the "loosely synchronous" programming model. Since the issues in concurrent programming reduces in many cases to the treatment of memory and communications, we discuss in detail graycodes, the distributed data structures, and low-level communications algorithms in the aforementioned system. We conclude with a generalization of memory allocation in support of multi-resolution image processing and compare the expected performance of the hypercube to pyramid computers.

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

3.56

A CONCURRENT ON-BOARD VISION SYSTEM FOR A MOBILE ROBOT

J. P. Jones

(Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988; Proc. Vol. II, pp. 1022-1032, Geoffrey Fox, Ed. (1988))

Robot vision algorithms have been implemented on an 8-node NCUBE-AT hypercube system on-board a mobile robot (HERMIES) developed at Oak Ridge National Laboratory. Images are digitized using a framegrabber mounted in a VME rack. Image processing and analysis are per-

formed on the hypercube system. The vision system is integrated with robot navigation and control software, enabling the robot to find the front of a mockup control panel, move up to the panel, and read an analog meter. Among the concurrent algorithms used for image analysis are a new component labeling algorithm and a Hough transform algorithm with load balancing.

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

3.57

THE BUTTERFLY ACCUMULATOR AND ITS APPLICATION IN CONCURRENT COMPUTER VISION ON HYPERCUBE MULTICOMPUTERS

J. P. Jones

(Abstract of oral presentation presented at the International Workshop on Concurrent Computer Vision, Aalborg, Denmark, January 25-27, 1989)

In concurrent programs the accumulation of data from all processors to a single location (gather) or the distribution of data from a single location to all processors (scatter) is frequently useful. An efficient algorithm exists for hypercube multicomputers which performs gather-scatter simultaneously to all processors in $\lg(N)$ time. Because of the isomorphism of the communications graph of this algorithm to that of the fast Fourier transform, we call this algorithm the "butterfly accumulator."

In this talk we demonstrate by example the generality of the butterfly accumulator by giving concurrent solutions for a variety of problems taken from image processing and analysis, including image scaling, histogramming, component labeling, relaxation labeling, simple load balancing, fast transforms, and some selected neural networks. We conclude with a discussion of the relationship of this communications algorithm to memory allocation in distributed multi-resolution images.

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

3.58

PARALLEL RELAXATION MATCHING**J. P. Jones K. M. Clinard***

(Abstract of paper presented at the 17th Workshop on Applied Imagery Pattern Recognition, Washington, DC, November 2-4, 1988)

Model based vision systems require correspondence between expectation and observation. One strategy for establishing this correspondence is relaxation matching. In relaxation matching, region features in segmented images and geometric relationships between regions are evaluated with respect to expectations established by a model. A set of possible matching regions are determined for each region of the model. These candidate matches are refined by a relaxation procedure until one or more have a highly likely assignment, which is then fixed. Other candidate matches are then re-evaluated in this context. The procedure is repeated until all model regions have firm assignments.

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

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3.59

A COMPUTER VISION SYSTEM FOR A HYPERCUBE CONCURRENT ENSEMBLE**J. P. Jones R. C. Mann
E. M. Simpson***

(Abstract of ORNL/TM-10679, August 1988)

A system of image processing and analysis utilities for a general-purpose hypercube topology concurrent multiprocessor system is described. The purpose of the system is to provide an efficient development and run-time environment for theoretical and experimental inquiry into computational vision for mobile and manipulative robots. An additional objective is to provide an environment with rich support for the development of concurrent computer vision algorithms. A number of principles for programming concurrent systems are embodied in the implementation of this system. In particular, all significant computation is performed by the hypercube proper, reserving the host processor exclusively for input/output func-

tions. One consequence of this principle is that applications are developed by viewing the concurrent multiprocessor as a single computer with a special internal structure, rather than as a number of independent machines. Applications derive from a single source, rather than many, reducing development time without sacrificing run-time efficiency. This document serves as an introduction to the image processing and analysis system, its principles of operation, and as a reference manual for its use.

Research sponsored by U.S. Department of Energy and U.S. Army Human Engineering Laboratory.

*University of West Florida, Pensacola, FL.

3.60

SENSOR INTEGRATION USING CONCURRENT COMPUTING ON-BOARD THE ORNL MOBILE ROBOT**R. C. Mann J. P. Jones
M. Beckerman C. W. Glover
L. Farkas* J. R. Einstein**

(Abstract of paper presented at the IEEE 1989 International Conference on Robotics and Automation, Scottsdale, AZ, May 14-19, 1989)

The mobile robot prototypes developed at the ORNL Center for Engineering Systems Advanced Research (CESAR) are equipped with sonar sensors, CCD cameras and a laser range camera that are used to support autonomous navigation and simple inspection tasks in an *a priori* unknown and unstructured dynamic environment. This paper summarizes work directed at extracting information from data collected with these sensors and integrating it, in order to produce reliable descriptions of the robot's environment. The approach consists in studying different world models and mappings among them, sensor models and parallel algorithms for sensor information processing, and appropriate integration strategies. Specifically, the paper describes the integration of two-dimensional vision and sonar range information and the integration of laser range and luminance images. All operations are carried out on-board the mobile robot using a 16-processor hypercube computer.

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

*Cornell University, Ithaca, NY.

OPTIMIZATION FOR INTELLIGENT SYSTEMS

3.61

YET ANOTHER NON-LINEAR APPROACH TO LINEAR- PROGRAMMING

J.-C. Culioli

(Abstract of oral presentation presented at the South Eastern Atlantic Section of SIAM Meeting, Knoxville, TN, March 18, 1989)

The recent success of Karmarkar's algorithm and of many related interior-path methods has revived the application of non-linear techniques to Linear Programming. In this talk, we consider another non-linear approach. We use an augmented Lagrangian primal-dual method and build several variants for which we discuss convergence to optimality and implementation issues.

Research sponsored by U.S. DOE and by U.S. Air Force Wright Aeronautical Laboratory.

3.62

DECOMPOSITION/COORDINATION ALGORITHMS IN CONVEX STOCHASTIC OPTIMIZATION

J.-C. Culioli G. Cohen*

(Abstract of paper presented at the SIAM Conference on Applied Linear Algebra, Minneapolis, MN, July 11-15, 1988)

Large scale systems are often imbedded in a stochastic environment. Their dimensionality usually prevents a global solution technique. Decomposition algorithms usually assume differentiability and separability of the global criterion. The deterministic Auxiliary Problem Principle proposed by G. Cohen does not require these properties. It also enables to solve the sub-problems separately with heterogeneous algorithmic techniques. We present here a generalization to the stochastic case. We address "price decomposition" and "resource allocation decomposition," state almost sure convergence results, and present some numerical tests on sequential and parallel computers.

Research sponsored by U.S. DOE Office of Military Applications and Office of Basic Energy Sciences and by U.S. Air Force Wright Aeronautical Laboratories.

*Ecole Nationale des Mines de Paris, Cedex, France.

3.63

DECOMPOSITION/COORDINATION ALGORITHMS IN STOCHASTIC OPTIMIZATION

J.-C. Culioli G. Cohen*

[Abstract of *SIAM Journal of Optimization* (in press)]

In this paper, we consider an extension to the situation of stochastic programming of the Auxiliary Problem Principle formerly introduced in a deterministic setting to serve as a general framework for decomposition/coordination optimization algorithms. The idea is based upon that of the stochastic gradient, that is, independent noise realizations are considered successively along the iterations. As a consequence, deterministic subproblems are solved at each iteration whereas iterations fulfill the two tasks of coordination and stochastic approximation at the same time. Coupling cost function (expectation of some performance index) and *deterministic* coupling constraints are considered. Price (dual) decomposition (encompassing extensions of the Uzawa and Arrow-Hurwicz algorithms to this stochastic case) are studied as well as resource allocation (primal decomposition).

Research sponsored by U.S. DOE and Air Force Wright Aeronautical Laboratory.

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3.64

NCUBE IMPLEMENTATION OF SOME HEURISTICS AND AN OPTIMAL ALGORITHM FOR LARGE-SCALE ASSIGNMENT PROBLEMS

J.-C. Culioli C. W. Glover
J. P. Jones C. Roe*

(Abstract of paper presented at the Fourth Conference on Hypercubes, Concurrent Computers and Applications, Monterey, CA, March 6-8, 1989)

We consider the standard Assignment problem: minimize: $z = \sum_i \sum_j c_{ij} x_{ij}$ subject to $\sum_i x_{ij} = 1$ and $\sum_j x_{ij} = 1$, where $1 \leq i \leq n$, $1 \leq j \leq m$, and $x_{ij} \in \{0,1\}$, and $c_{ij} \geq 0$. We are specially interested in large scale problems such that n and $m \geq 100$. We describe and compare several ap-

proaches, some of them being well-known heuristics to initiate a Transportation problem such as the Least Cost Rule and Vogel's Approximation Method, others being optimal methods such as the Hungarian Method. For each algorithm, our study focuses on two major issues; the parallel implementation strategies on hypercube concurrent computers and the solution optimality given the computational load. We describe implementations on an NCUBE (Beaverton, OR) hypercube. We also propose some decision scenarios using a combination of different heuristics in order to get as fast as possible sub-optimal solutions.

Research sponsored by U.S. DOE Office of Nuclear Energy, Technology Support Programs and by U.S. Air Force Wright Aeronautical Laboratory.

*Loyola University, New Orleans, LA.

3.65

A NEW ALGORITHM FOR LINEAR PROGRAMMING THAT IS EASY TO IMPLEMENT: APPLICATION TO THE TRANSPORTATION PROBLEM

J.-C. Culioli V. Protopopescu

(Abstract of ORNL/TM-10929, September 1988)

We propose a new algorithm for linear programming and apply it to solve some transportation problems. We prove the convergence of the algorithm under reasonable sufficient conditions. The main motivation of this new linear-programming solver is its extreme simplicity and its parallel structure which allows for straightforward implementations on personal computers as well as on more sophisticated machines. We give in the Appendix a version of the algorithm programmed in C in less than 30 lines. We also comment in the Appendix the relationship of our algorithm with some models of neural networks.

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

3.66

AN ALGORITHM FOR LINEAR PROGRAMMING THAT IS EASY TO IMPLEMENT

J.-C. Culioli V. Protopopescu

(Abstract of *Appl. Math. Lett.* 2(2), 125 (1989))

We present a new linear-programming algorithm that is simple, effective, fully parallelizable, and immediately implementable on personal computers as well as on more sophisticated machines. Sufficient conditions are found that guarantee the convergence of the algorithm. Some applications are given showing that the applicability of the algorithm is actually wider than indicated by the theoretical results.

Research sponsored by U.S. DOE and by the U.S. Air Force Wright Aeronautical Laboratory.

3.67

BIFURCATING OPTIMIZATION ALGORITHMS AND THEIR POSSIBLE APPLICATION

J.-C. Culioli V. Protopopescu

(Abstract of ORNL/TM-10976, November 1988)

A new class of optimization algorithms for linear and nonlinear problems is proposed. The algorithms are based on sigmoidic updatings and can be looked upon as nonlinear multidimensional maps. The bifurcation and chaotic regimes of these maps are analyzed and their possible applications in optimization problems are indicated.

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

3.68

SIGMOIDIC LINEAR AND NON-LINEAR OPTIMIZATION ALGORITHMS

J.-C. Culioli V. Protopopescu

(Abstract of paper presented at the International Neural Network Society Annual Meeting, Boston, MA, September 6-10, 1988)

Since Hopfield and Tank have proposed their neural network based computation method to solve optimization combinatorial problems, a significant amount of work has been done to apply it to a great number of difficult problems, with various degrees of success. Here, we address continuous optimization and propose neural network models for linear and non-linear optimization.

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

3.69

A NEW CLASS OF OPTIMIZATION ALGORITHMS WITH BIFURCATIONS AND CHAOTIC BEHAVIOR

J.-C. Culioli V. Protopopescu

(Abstract of paper presented at the SIAM Conference on Applied Linear Algebra, Minneapolis, MN, July 11-15, 1988)

We introduce a new class of optimization algorithms that use parameter dependent sigmoidic functions to limit the sequence of iterates. For Linear-Programming, the proposed scheme converges to a close approximation of the solution for small parameter values. For the (constrained or unconstrained) non-linear case, the optimal solution is a stable fixed point of the algorithm. In both cases, if the design parameter is "very small," the sequence of iterates shows bifurcations and ultimately chaotic behavior. We conjecture that this typical property could be used to compute very quickly a satisfactory approximation of the sought optimal solution.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Military Applications and by U.S. Air Force Wright Aeronautical Laboratories.

3.70

A LINEAR-PROGRAMMING METHOD INSPIRED BY THE NEURAL NETWORKS FRAMEWORK

J.-C. Culioli V. Protopopescu

(Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, July 24-27, 1988)

We propose a discrete numerical algorithm for linear programming that has common features with non-linear optimization algorithms and with neural network models. The "computation energy" of our algorithm is not quadratic, but linear, which greatly simplifies the model. The collective computational properties are obtained by dividing the neurons in two classes: primal and dual. The algorithm is parallelisable, easier to code than most classical linear-programming algorithms, and implementable in VLSI. The relationship with other neural network models is discussed.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Military Applications and by U.S. Air Force Wright Aeronautical Laboratories.

3.71

STABILITY AND CHAOS IN A NUMERICAL SCHEME INSPIRED BY NEURAL NETWORKS

J.-C. Culioli V. Protopopescu

(Abstract of oral presentation presented at the Workshop of the AAAS in Corvallis, OR, June 20, 1988)

We address some new non-linear optimization algorithms based on a neural network model with sigmoidic updating. The iteration used to minimize the unconstrained convex function $F(x)$ is realized through the non-linear mapping: $x(k+1) = h(x(k))$ with $h(x) = 2x / (1 + \exp[F'(x)/T])$, where T is a positive parameter and F' is the derivative of F . When varying T , we observe the full scenario of bifurcations and chaotic behavior of the mapping and we investigate the Lyapunov exponents and the stability properties associated to it. We show that, in some cases, the cyclic behavior can be used to get fast approximations of the sought optimal solution. We also vary T (a form of annealing scheme) in order to find the solution before entering chaos.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Office of Military Applications and by U.S. Air Force Wright Aeronautical Laboratories.

3.72

NEURAL NETWORKS MODELS FOR LINEAR PROGRAMMING

J.-C. Culioli V. Protopopescu
C. Britton* N. Ericson*

(Abstract of paper to be presented at the International Joint Conference on Neural Networks, Washington, DC, January 15-19, 1990)

The purpose of this paper is to present a neural network that solves the general Linear Programming (LP) problem. In the first part, we recall Hopfield and Tank's circuit for LP and show that although it converges to stable states, it does not, in general, yield admissible solutions. This is due to the penalization treatment of the constraint. In the second part, we propose an approach based on Lagrange multipliers that converges to primal and dual admissible solutions. We also show that the duality gap (measuring the optimality) can be rendered, in principle, as small as needed.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratory and U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

3.73

A NEURAL NETWORK FOR BOUNDED LINEAR PROGRAMMING

J.-C. Culioli V. Protopopescu
C. Britton* N. Ericson*

(Abstract of paper to be presented at the International Joint Conference on Neural Networks, Washington, DC, January 15-19, 1990)

The purpose of this paper is to describe a neural network implementation of an algorithm recently designed at ORNL to solve the Transportation and the Assignment Problems, and, more generally, any explicitly bounded linear program.

Research sponsored by U.S. Air Force Wright Aeronautical Laboratory and U.S. DOE Office of Basic Energy Sciences.

*Instrumentation and Controls Division.

3.74

A COMPARISON STUDY OF OPTIMIZATION METHODS FOR THE BIPARTITE MATCHING PROBLEM (BMP)

M. Goldstein* N. Toomarian†
J. Barhen‡

(Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, July 24-27, 1988; Proc. Vol. II, pp. 267-273 (1988))

A comparison study of optimization methods for the bipartite matching problem (BMP) with independent random distances between the points is presented. It is concluded that a variant of simulated annealing, developed at ORNL, is the most promising for the BMP.

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

*On leave from Nuclear Research Centre-Negev, Israel.

†Omninet Communications Services, Los Angeles, CA.

‡Jet Propulsion Laboratory, Pasadena, CA.

3.75

A CONCURRENT NEURAL NETWORK ALGORITHM FOR THE TRAVELING SALESMAN PROBLEM

N. Toomarian*

(Abstract of paper presented at the Third Conference on Hypercube Concurrent Computers and Applications, Pasadena, CA, January 19-20, 1988; Proc. Vol. II, pp. 1483-1490, Geoffrey Fox, Ed. (May 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, is reduced from Hopfield and Tank's $O(N^2)$ to $O(M \log_2 N)$. A continuous synchronous neural network algorithm, in conjunction with the Lagrange multiplier, is used to solve the problem. The algorithm has been implemented on the NCUBE hypercube multiprocessor. This algorithm converges faster and has a higher probability to reach a valid tour than previously available results.

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

*Omninet Communications Services, Los Angeles, CA.

3.76

A NEURAL NETWORK-BASED OPTIMIZATION ALGORITHM FOR THE WEAPON-TARGET ASSIGNMENT PROBLEM

E. Wacholder

(Abstract of ORNL/TM-11025, February 1989)

A neural network-based algorithm was developed for the Weapon-Target Assignment Problem (WTAP) in Ballistic Missile Defense (BMD). An optimal assignment policy is one which allocates targets to weapon platforms such that the total expected leakage value of targets surviving the defense is minimized. This involves the minimization of a non-linear objective function subject to inequality constraints specifying the maximum number of interceptors available to each platform and the maximum number of interceptors allowed to be fired at each target as imposed by the Battle Management/Command Control and Communications (BM/C³) system. The algorithm consists of solving a system of ODEs trajectories and variables. Simulations of the algorithm on PC and VAX computers were carried out using a simple numerical scheme. In all the battle instances tested, the algorithm has proven to be stable and to converge to solutions very close to global optima. The time to achieve convergence was consistently less than the time constant of the network's processing elements (neurons). This implies that fast solutions can be realized if the algorithm is implemented in hardware circuits. Three series of battle scenarios are analyzed and discussed in this report. Input data and results are presented in detail. The main advantage of this algorithm is that it can be adapted to either a special-purpose hardware circuit or a general-purpose concurrent machine to yield fast and accurate solutions to difficult decision problems.

Research sponsored by the Office of Military Applications of the U.S. Department of Energy and by the U.S. Air Force Wright Aeronautical Laboratories.

3.77

AN EXTENSION OF THE HOPFIELD TANK MODEL FOR SOLUTION OF THE MULTIPLE TRAVELING SALESMEN PROBLEM

**E. Wacholder J. Han
R. C. Mann**

[Abstract of paper presented at the IEEE International Conference on Neural Networks, San Diego, CA, July 24-27, 1988; Proc. Vol. II, pp. 305-324 (1988)]

We developed an efficient neural network algorithm for solving the Multiple Traveling Salesmen Problem (MTSP). A new transformation of the N-City, M-salesmen MTSP to the standard Traveling Salesmen Problem (TSP) is introduced. The transformed problem is represented by an expanded version of Hopfield-Tank's neuromorphic city-position map with $(N+M-1)$ -city and a single fictitious salesman. The dynamic model associated with the problem is based on the Basic Differential Multiplier Method (BDMM). The algorithm was successfully tested on many problems with up to 30 cities and 5 salesmen. In all test cases, the algorithm always converged to valid solutions.

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

3.78

A NEURAL NETWORK ALGORITHM FOR THE MULTIPLE TRAVELING SALESMEN PROBLEM

**E. Wacholder J. Han
R. C. Mann**

(Abstract of ORNL/TM-10799, November 1988; also *Biol. Cybern.* 61, 11-19 (1989))

We developed an efficient neural network algorithm for solving the Multiple Traveling Salesmen Problem (MTSP). A new transformation of the N-city, M-salesmen MTSP to the standard Traveling Salesmen Problem (TSP) is introduced. The transformed problem is represented by an expanded version of Hopfield-Tank's neuromorphic city-position map with $(N+M-1)$ -city and a single fictitious salesman. The dynamic model associated with the problem is based on the Basic Differential Multiplier Method (BDMM) which evalu-

ates Lagrange multipliers simultaneously with the problem's state variables. The algorithm was successfully tested on many problems with up to 30 cities and five salesmen. In all test cases, the algorithm always converged to valid solutions. The great advantage of this kind of algorithm is that it can provide solutions to complex decision making problems directly by solving a system of ordinary differential equations. No learning steps, logical if statements or adjusting of parameters are required during the computation. The algorithm can therefore be implemented in hardware to solve complex constraint satisfaction problems such as the MTSP at the speed of analog silicon VLSI devices or possibly future optical neural computers.

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

3.79

A NEURAL NETWORK ALGORITHM FOR THE TARGET-WEAPON ASSIGNMENT PROBLEM

**E. Wacholder J. Han
R. C. Mann**

[Abstract of paper presented at the International Neural Network Society Annual Meeting, Boston, MA, September 6-10, 1988; Proc. Vol. 1, Supplement 1, p. 147 (1988)]

A neural network algorithm was developed to solve the problem of Weapon-Target Assignment

(WTA) for space-based Kinetic Energy Weapons (KEWs) against Intercontinental Ballistic Missiles (ICBMs). We consider here only the static version of this problem for a completely known attack scenario within a given time. The analytical model is an extended version of the Hopfield-Tank model combined with the Basic Differential Multiplier Method (BDMM) to solve for LaGrange multipliers simultaneously with the problem's state variables. Results obtained show the validity of the proposed model for large-scale WTA problems. Computation time can be extremely short with hardware implementation using neuromorphic devices or possibly future optical neural computers.

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

AUTOMATED METHODS FOR SENSITIVITY AND UNCERTAINTY ANALYSIS

3.80

GRESS ADJOINT MATRIX REDUCTION ALGORITHMS

J. E. Horwedel*

[Abstract of *Trans. Am. Nucl. Soc.* 60, 590 (1989)]

GRESS is an efficient automated software system for calculating sensitivities of model results to input data in existing FORTRAN 77 computer models. The GRESS ADGEN option calculates first derivatives of selected model results with respect to an almost unlimited amount of data by application of the adjoint method. However, data storage has been a major limiting factor. The data

storage requirement for an ADGEN application was more than 332 megabytes for a code that executes in 1 minutes on a VAX 8600 computer. The purpose of this paper is to describe two new algorithms that dramatically reduce the data storage requirement and execution time for application of the ADGEN option.

Research sponsored by U.S. DOE Office and Nuclear Regulatory Commission.

*Computing and Telecommunications Division.

3.81

EXAP—PRECOMPILER FOR THE GRESS AND ADGEN AUTOMATED SENSITIVITY CALCULATION SYSTEMS

J. E. Horwedel* F. G. Pin
B. A. Worley

[Abstract of *Trans. Am. Nucl. Soc.* 56, 301 (1988)]

In recent years, two automated systems have been developed that add derivative taking capability to existing FORTRAN codes. The derivative information is used to calculate sensitivities of model results to input data. The two systems, GRESS and ADGEN, solve the forward and adjoint sensitivity problems, respectively. Both systems are based on a precompiler that automates the calculation of derivatives of the real variable on the left-hand side (LHS) of each equation with respect to the real variables on the right-hand side (RHS) of each equation. This paper describes the features of the extended arithmetic processor (EXAP) precompiler that makes the automation of differentiation capability practical.

Research sponsored by U.S. DOE Office of Salt Repository Project.

*Computing and Telecommunications Division.

3.82

GRESS VERSION 0.0 USER'S MANUAL

J. E. Horwedel* B. A. Worley
E. M. Oblow F. G. Pin
R. Q. Wright*

(Abstract of ORNL/TM-10835, October 1988)

This manual provides a description of the Gradient Enhanced Software System (GRESS) and explains how to use it to enhance FORTRAN 77 models for gradient calculations. The use of the Extended Arithmetic Processor (EXAP) as the precompiler for GRESS is presented. A complete description of how to enhance a source code for forward propagation of derivatives using the calculus chain rule is provided. On option, EXAP can be used to generate derivatives and store them on a direct access device for subsequent solution of the

numerical adjoint equations. Programming information is also provided to aid in the installation and maintenance of the software.

Research sponsored by U.S. DOE Office of Defense Waste and Environmental Restoration.

*Computing and Telecommunications Division.

3.83

COMPARISON OF RESULTS BASED ON A DETERMINISTIC VERSUS A STATISTICAL UNCERTAINTY ANALYSIS

R. E. Maerker

(Abstract of ORNL/TM-10773, May 1988)

A deterministic method for performing an uncertainty analysis is applied to the results of a system of three codes previously analyzed by purely statistical means. This new method propagates parameter joint probabilities through computer models to obtain the distributions of model results by linear extrapolation from a pool of several gradient-enhanced reference runs. Results employing various options in the method are tested against those from the earlier statistical treatment. Both point-by-point and cumulative distribution comparisons were generally performed. This effort leads to the conclusion that in the present application 15 gradient-enhanced runs provide virtually as much uncertainty information as 200 statistical executions of the code system, and this feature of the analysis is expected to remain generally valid for most types of problems. The advantage of significant reduction in the number of reference runs required by the deterministic method is partially offset by the longer execution times of the enhanced versions of the codes, however. Thus efficient derivative-taking algorithms will be necessary to insure cost effectiveness.

Research sponsored by U.S. DOE Office of Nuclear Waste Isolation.

3.84

DEVELOPMENT AND APPLICATION OF A NEW DETERMINISTIC METHOD FOR CALCULATING COMPUTER MODEL RESULT UNCERTAINTIES

R. E. Maerker B. A. Worley

[Abstract of *Trans. Am. Nucl. Soc.* 60, 591 (1989)]

Interest in research into the field of uncertainty analysis has recently been stimulated as a result of a need in high-level waste repository design assessment for uncertainty information in the form of response complementary cumulative distribution functions (CCDF's) to show compliance with regulatory requirements. The solution to this problem must obviously rely on analysis of computer code model which, however, employ parameters that can have large uncertainties.

The motivation for the research presented here is a search for a method involving a deterministic uncertainty analysis approach which could serve as an improvement over those methods that make exclusive use of statistical techniques.

A deterministic uncertainty analysis (DUA) approach based on the use of first derivative information is the method studied in the present procedure. Since deterministic sensitivity methods have been shown in the past to be a cost efficient and practical means for determining derivative and sensitivity information, the possibility arises that the DUA approach could lead to a substantial reduction in the number of model runs compared to conventional analysis.

Research sponsored by U.S. DOE Office of Fusion Energy and Defense Nuclear Agency.

3.85

ANALYTICAL METHODS FOR LARGE-SCALE SENSITIVITY ANALYSIS USING GRESS AND ADGEN

F. G. Pin

(Abstract of paper presented at the 1988 Workshop on High Level Waste Disposal, Stockholm, Sweden, April 11-14, 1988)

Sensitivity analysis is an established methodology used by researchers in almost every field to gain essential insight in design and modeling stud-

ies 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 ADGEN 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 National Low-Level Waste Management Program.

3.86

SENSITIVITY ANALYSIS OF TWO-PHASE FLOW PROBLEMS

N. Toomarian* E. Wacholder
S. Kaizerman†

[Abstract of *Nucl. Sci. Eng.* 99, 53 (1988)]

The mathematical derivation and application of two deterministic sensitivity analysis methods, the direct approach of sensitivity (DAS) and the adjoint sensitivity method (ASM), are presented for two-phase flow problems. The physical problems investigated are formulated by the transient one-dimensional two-phase flow diffusion model, which consists of a system of four coupled quasi-linear first order partial differential equations. The DAS method provides the sensitivity coefficients of all primary dependent variables at each time and space location with respect to a single input parameter. On the other hand, the ASM method provides the sensitivity coefficients of a single response function at a specified time and space location with respect to all input parameters.

The systems of governing equations of both sensitivity methods developed possess the same characteristic directions as those of the original physical model. Therefore, the same numerical methods for the solution of these equations have been selected as for the solution of the physical problem, i.e., Turner scheme and Modified Turner (NAIAD) scheme. Special techniques to incorpo-

rate the boundary conditions of the ASM governing equations for each numerical scheme were developed. The sensitivity coefficients computed by both methods have been verified against results from standard parametric studies. Two sample problems are thoroughly investigated. The first problem considers the transient fluid behavior in a uniformly heated channel subjected to an inlet flow decay. The second problem considers the transient fluid response within the same channel when a pressure step change at the channel inlet is imposed. Both methods predict satisfactorily the sensitivity coefficient behavior in space and time in comparison with parametric studies, even when a moving boiling boundary exists within the flow field. Certain coefficients in the thermodynamic correlations of the liquid density and the liquid saturation enthalpy, as well as the boundary conditions of the problems, were found to be the most "sensitive" input parameters in both problems investigated. Some input parameters of minor significance in the steady-state conditions were found to be very "influential" during the transient and vice-versa. The behavior of most of the sensitivity coefficients, in space and time, cannot be estimated without a systematic sensitivity analysis method.

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

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†Israel Institute of Technology, Israel.

3.87

A FORTRAN PRECOMPILER AND SYSTEM FOR AUTOMATING THE IMPLEMENTATION OF THE FORWARD AND ADJOINT DETERMINISTIC SENSITIVITY METHODS INTO EXISTING FORTRAN COMPUTER CODES

B. A. Worley

(Abstract of oral presentation presented at Los Alamos National Laboratory, Los Alamos, NM, April 27, 1988)

This talk reports on the development of a Gradient-Enhanced Software System (GRESS) that makes use of computer calculus precompilers to automate the implementation of deterministic sensitivity analysis into existing FORTRAN computer models. This automation removes the considerable programming effort required for im-

plementation of the forward and adjoint sensitivity methods by directly changing the model. Deterministic sensitivity theory, the GRESS system, and sample problem results will be addressed.

Research sponsored by U.S. DOE National Low-Level Waste Management Program Office of Defense Waste and Environmental Restoration.

3.88

CALCULATION AND USE OF COMPUTER MODEL DERIVATIVES

B. A. Worley

(Abstract of paper presented at the SIAM Conference on Optimization, Boston, MA, April 3-5, 1989 and at a Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3-5, 1988)

The calculation of derivatives of computer model results with respect to model data is performed using GRESS, a system of routines that enhances existing FORTRAN computer codes with the capability to analytically compute derivatives of interest in addition to normal model results. The feasibility and cost of calculating derivatives by both the direct chain rule and the adjoint options within GRESS and exemplified by the application of GRESS to a large-scale computer code that models radionuclide transport. The use of the derivative information for performing sensitivity analysis, in the formation of response surfaces, and in optimization applications is presented.

Research sponsored by U.S. DOE National Low-Level Waste Management Program.

3.89

ADGEN - ADJOINT GENERATOR FOR COMPUTER MODELS

**B. A. Worley F. G. Pin
J. E. Horwedel* E. M. Oblow**

(Abstract of ORNL/TM-11037, May 1989)

This paper presents the development of a FORTRAN compiler and an associated supporting software library called ADGEN. ADGEN reads FORTRAN models as input and produces an enhanced version of the input model. The enhanced version reproduces the original model

calculations but also has the capability to calculate derivatives of model results of interest with respect to any and all of the model data and input parameters. The method for calculating the derivatives and sensitivities is the adjoint method. Partial derivatives are calculated analytically using computer calculus and saved as elements of an adjoint matrix on direct access storage. The total derivatives are calculated by solving an appropriate adjoint equation. ADGEN is applied to a major computer model of interest to the Low-Level Waste Community, the PRESTO-II model. PRESTO-II sample problem results reveal that ADGEN correctly calculates derivatives of a response of interest with respect to 3000 parameters. The execution time to create the adjoint matrix is a factor of 45 times the execution time of the reference sample problem. Once this matrix is determined, the derivatives with respect to 3000 parameters are calculated in a factor of 6.8 that of the reference model for each response of interest. For a single response, the total factor of 51.8 compares to a factor of 3000 for determining these derivatives by parameter perturbations. The automation of the implementation of the adjoint technique for calculating derivatives and sensitivities eliminates the costly and manpower-intensive task of direct hand-implementation by reprogramming and thus makes the powerful adjoint technique more amenable for use in sensitivity analysis of existing models.

Research sponsored by U.S. DOE National Low-Level Waste Management.

*Computing and Telecommunications Division.

3.90

DETERMINISTIC SENSITIVITY AND UNCERTAINTY ANALYSIS FOR LARGE SCALE COMPUTER MODELS

B. A. Worley F. G. Pin
E. M. Oblow R. E. Maerker
J. E. Horwedel* R. Q. Wright*

[Abstract of paper presented at the Tenth Annual DOE Low-Level Radioactive Waste Management Conference, Denver, CO, August 30-September 1, 1988, Session II: Site Performance Assessment, Proc. p. 126 (December 1988); and at the NEA Probabilistic System Assessment Codes User Group Meeting, Paris, France, November 29-December 2, 1988]

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. This 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.

Research sponsored by U.S. DOE National Low-Level Waste Management Program Office of Defense Waste and Environmental Restoration.

*Computing and Telecommunications Division.

ADVANCED CARBOLS PROGRAM

3.91

AN INTELLIGENT SIMULATION ENVIRONMENT FOR CONTROL SYSTEM DESIGN

J. T. Robinson

[Abstract of paper presented at the 1989 Eastern Multiconference, Tampa, FL, March 28-31, 1989; Proc. *Advances in AI and Simulation* 20(4), pp. 28-32 (March 1989); also 7th Power Plant Dynamics, Control, and Testing Symposium, Knoxville, TN, May 15-17, 1989; Proc. pp. 3.01-3.12 (May 1989)]

The Oak Ridge National Laboratory is currently assisting in the development of advanced control systems for the next generation of nuclear power plants. This paper presents a prototype interactive and intelligent simulation environment being developed to support this effort. The environment combines tools from the field of Artificial Intelligence; in particular object-oriented programming, a LISP programming environment, and a direct manipulation user interface; with traditional numerical methods for simulating combined continuous/discrete processes. The resulting environment is highly interactive and easy to use. Models may be created and modified quickly through a window oriented direct manipulation interface. Models may be modified at any time, even as the simulation is running, and the results observed immediately via real-time graphics.

Research sponsored by U.S. DOE Office of Reactor Technologies Development.

3.92

AN INTELLIGENT DYNAMIC SIMULATION ENVIRONMENT: AN OBJECT-ORIENTED APPROACH

J. T. Robinson R. A. Kisner*

[Abstract of paper presented at the Third IEEE International Symposium on Intelligent Control, Arlington, VA, August 24-26, 1988; Proc. H. E. Stephanou, A. Meystel, and J. Y. S. Luh, Eds., pp. 687-692 (1989)]

This paper presents a prototype simulation environment for nuclear power plants which illustrates the application of object-oriented programming to process simulation. Systems are modeled using this technique as a collection of objects

which communicate via message passing. The environment allows users to build simulation models by selecting iconic representations of plant components from a menu and connecting them with the aid of a mouse. Models can be modified graphically at any time, even as the simulation is running, and the results observed immediately via real-time graphics. This prototype illustrates the use of object-oriented programming to create a highly interactive and automated simulation environment.

Research sponsored by U.S. DOE Office of Reactor Technologies Development.

*Instrumentation and Controls Division.

3.93

AN APPLICATION OF OBJECT ORIENTED PROGRAMMING TO PROCESS SIMULATION

J. T. Robinson P. J. Otaduy

[Abstract of paper presented at the National Meeting of the American Institute of Chemical Engineers, Denver, CO, August 22-25, 1988]

This paper discusses the application of object-oriented programming to dynamic simulation of continuous processes. Processes may be modeled using this technique as a collection of objects which communicate with each other via message passing. Arriving messages invoke methods that describe the state and/or dynamic behavior of the receiving object. The objects fall into three broad categories (1) actual plant components such as pumps, pipes, and tanks, (2) plant systems such as flow loops, and (3) simulation control and interface objects. This technique differs from traditional approaches to process simulation, in which the process is represented by either a system of differential equations or a block diagram of mathematical operators. The use of objects minimizes the representational gap between the model and the actual process. From the users point of view, construction of a simulation model becomes equivalent to drawing a plant schematic.

As an example application, a package developed for the simulation of nuclear power plants is described. The package allows users to build simulation models by selecting iconographic repre-

sentations of plant components from a menu and connecting them with a mouse. Objects for generating and optimizing a mathematical model of the system and for controlling the simulation are automatically generated. This example illustrates the use of object-oriented programming to create a highly interactive and automated simulation environment.

Research sponsored by U.S. DOE Office of Reactor Technologies Development.

3.94

VOID DISTRIBUTIONS IN BUBBLY FLOW THROUGH YAWED ROD ARRAYS

J. T. Robinson N. E. Todreas*
D. Ebeling-Koning†

[Abstract of *Int. J. Multiphase Flow* 14, 645-652 (1988)]

In this communication, observations of void distribution in bubbly flow through an array of rods inclined relative to the average flow direction are presented. The experiments reveal a strong dependence of void distribution on bubble size and rod arrangement. It is postulated that this dependence is due to the entrapment and migration of bubbles in vortices behind the rods. Not surprisingly, attempts to simulate the experimental results with a six-equation porous-body model in which localized phenomenon such as vortices have been averaged out were unsuccessful.

Research sponsored by U.S. DOE Office of Basic Energy Sciences and Massachusetts Institute of Technology.

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†Westinghouse Electric Corporation, Pittsburgh, PA.

3.95

HIERARCHICAL CONTROL OF A NUCLEAR REACTOR USING UNCERTAIN DYNAMICS TECHNIQUES

L. A. Rovere* P. J. Otaduy
C. Britton† R. B. Perez

[Abstract of paper presented at the Third IEEE International Symposium on Intelligent Control, Arlington, VA, August 24-26, 1988; Proc. H. E. Stephanou, A. Meystel, and J. Y. S. Liu, Eds., pp. 713-718 (1989)]

Recent advances in the nonlinear optimal control area are opening new possibilities towards its implementation in process control. Algorithms for multivariate control, hierarchical decomposition, parameter tracking, model uncertainties, actuator saturation effects and physical limits to state variables can be implemented on the basis of a consistent mathematical formulation.

In this paper, good agreement is shown between a centralized and a hierarchical implementation of a controller for a hypothetical nuclear power plant subject to multiple demands.

The performance of the hierarchical distributed system in the presence of localized subsystem failures is analyzed.

Research sponsored by U.S. DOE Office of Reactor Technologies Development.

*Comision Nacional Energia Atomica, Argentina.

†Instrumentation and Controls Division.

3.96

DEVELOPMENT OF AN UNCERTAIN MODEL BASED NONLINEAR OPTIMAL PRESSURE CONTROL SYSTEM FOR A NUCLEAR REACTOR

L. A. Rovere* P. J. Otaduy
C. March-Leuba†

(Abstract of paper presented at the IEEE 1988 Nuclear Science Symposium, Orlando, FL, November 9-11, 1988)

Using nonlinear optimal control theory for uncertain systems, an algorithm has been developed to control reactor primary pressure and estimate the imbalance between power source and heat sink by observation of the pressure signal alone.

The algorithm was tested with a simulation of ORNL's High Flux Isotope Reactor (HFIR)

primary pressure boundary. The HFIR operates in a feed-and-bleed "solid" mode, where constant speed pressurizing pumps supply make-up flow and a bleed valve adjusts the system's letdown flow. The controller's internal model of the process is purposely less detailed than that of the simulation but incorporates a time dependent term to account for unknown effects. Using Pointryagin's Maximum Principle and the appropriate Hamiltonian a control algorithm is generated that from the difference between the measured pressure and

the internally computed one, it not only generates the correct bleed valve control signal needed to follow a time dependent pressure setpoint but it also identifies the magnitude and temporal behavior of the energy inventory in the primary system.

Research sponsored by U.S. DOE Office of Reactor Technologies Development.

*Comision Nacional Energia Atomica, Argentina.

†The University of Tennessee, Knoxville, TN.

ENERGY ANALYSIS

3.97

ESTIMATING FINDING RATES FOR U.S. CRUDE OIL

D. S. Christiansen* D. B. Reister

[Abstract of ORNL/TM-10897, October 1988; also *Energy* (in press)]

In this report we provide estimates of both exploratory and developmental finding rate equations for crude oil for six onshore regions in the lower 48 United States. We estimate the finding rate in two different ways — one based on the relationship between the finding rate and cumulative reserve additions (a "derivative approach") and one based on the relationship between cumulative reserve additions and cumulative drilling (an "integral approach"). We develop the integral approach according to two different methods. We investigate differences in finding rates between approaches and between regions. The regional data set is included as an appendix.

Research sponsored by U.S. DOE Office of Planning and Environment Office of Fossil Energy.

*Albion College, Albion, MI.

3.98

THE AGGREGATE PRODUCTION PROFILE FOR U.S. CRUDE OIL

D. S. Christiansen* D. B. Reister

[Abstract of ORNL/TM-10857, October 1988; also *Resources and Energy Journal* (in press)]

In this paper we estimate the aggregate production profile for U.S. crude oil for the period 1961 to 1985. Using data on reserves, we find that there is a significant lag between the time that reserves are added and the time production peaks. We attribute this long lag to a system of production controls that existed until about 1970. When we re-estimate over the period from 1970 to 1985, we find that there is a much shorter period between reserve additions and peak production. We consider an alternative approach based on drilling data that gives similar results for the entire sample period but different results for the subperiod 1970-1985. We discuss the factors that are responsible for the general shapes of the profiles we estimate.

Research sponsored by U.S. DOE-Fossil Energy, Office of Planning and Environment and by the Faculty Research Participation Program administered by Oak Ridge Associated Universities.

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3.99

OIL VULNERABILITY AND INTERMEDIATE PRICE FLUCTUATIONS: A PRELIMINARY ASSESSMENT AND PROPOSAL

T. R. Curlee* D. B. Reister

(Abstract of ORNL/TM-11259, September 1989)

Most of the work on oil vulnerability has focused on the implications and appropriate public and private responses to short-term oil price spikes. This paper focuses on the possibility that the world oil market is inherently more prone to large intermediate price fluctuations that are often triggered by short-term disturbances.

The purposes of this paper are (1) to pose the question of whether large and repeated intermediate price swings are a likely outcome, given our knowledge of the world oil market, (2) to address how the effectiveness of policy instruments designed to mitigate the impacts of oil vulnerability may change in a world in which large intermediate oil price fluctuations are expected, and (3) to propose future research that would address in greater detail the potential for, and appropriate responses to, large intermediate price swings on the world and domestic oil markets.

The paper concludes that there are plausible conceptualizations under which oil prices may fluctuate over the intermediate term. It is suggested that a major focus of future work should be on how the structure of the oil market may itself change over time, causing oil prices to go up and down. The paper also concludes that the implications for such price swings may be significant for both the types and quantities of mitigation measures held by the public and private sectors. Finally, it is argued that the current world oil market provides a valuable opportunity for studying how oil prices may fluctuate over the intermediate term and how U.S. energy policies can best be structured to cope with oil vulnerability.

Research sponsored by U.S. Department of Energy.

*Energy Division.

3.100

ENERGY TECHNOLOGY R&D: WHAT COULD MAKE A DIFFERENCE?

**W. Fulkerson* S. I. Auerbach†
A. T. Crane‡ D. E. Kash§
A. M. Perry* D. B. Reister
C. W. Hagan, Jr.***

(Abstract of ORNL-6541/V1, May 1989)

The objective of this study was to survey both energy technologies and crosscutting areas of science and technology in order to identify important R&D needs and opportunities in the context of the U.S. and world energy situations. The imperative for R&D was judged against its potential for fixing current energy system problems; for providing a robust set of options for coping with, taking advantage of, or encouraging future energy circumstances; and for creating unanticipated opportunities.

Research sponsored by U.S. Department of Energy.

*Energy Division.

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3.101

GLOBAL WARMING — AN ENERGY TECHNOLOGY R&D CHALLENGE

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[Abstract of Science 246, 868 (1989)]

Two major uncertainties preclude gaining a clear picture of future energy technology needs: (i) growth of energy demand, particularly of oil, and (ii) the seriousness and urgency of the changing greenhouse effect and of other environmental, health, and safety problems. To allow for these uncertainties, a broad research and development (R&D) effort is needed; one that is balanced with respect to emphasis on improved energy sources and improved efficiency of energy end-use and conversion. A recent Oak Ridge National Laboratory (ORNL) survey of energy technology R&D

revealed a rich variety of opportunities for improving both end-use and supply technologies. It also concluded that the U.S. effort is sufficiently broad since combined public and private sector investments are covering most of the promising energy technology options at some level.

Nevertheless the effort is inadequate. None of the nonfossil energy sources are yet ready to substitute competitively at the scale necessary to reduce CO₂ emissions. To correct this inadequacy, a three prong R&D strategy is required: improve the efficiency of energy conversion and use, improve nonfossil energy sources, and improve technologies tailored to the needs of developing nations.

Research sponsored by U.S. DOE.

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§Environmental Sciences Division.

3.102

ENERGY TECHNOLOGY R&D: WHAT COULD MAKE A DIFFERENCE

D. B. Reister

(Abstract of paper presented at the Technology-Based Confidence Building: Energy and Environment, Santa Fe, NM, July 9-14, 1989; and at the MIT Workshop on Energy and Environmental Modeling and Policy Analysis, Cambridge, MA, July 31-August 1, 1989)

Two major uncertainties cloud the future energy system: the level of energy demand and the consequences of the greenhouse effect. Energy technology R&D provides technological alternatives for the future energy system. The Oak Ridge National Laboratory (ORNL) recently completed a broad survey of energy technology R&D. The survey revealed a rich variety of options for both end-use technologies and energy supply technologies. However, none of the nonfossil energy sources are ready to substitute for fossil fuels at the scale necessary to mitigate the potential consequences of the greenhouse effect.

Research sponsored by U.S. Department of Energy.

3.103

FUTURE EMISSIONS OF CARBON DIOXIDE: CAN WE MAKE A DRAMATIC REDUCTION?

D. B. Reister

(Abstract of paper presented at the WATtec Conference, Knoxville, TN, February 16, 1989)

The hot and dry summer of 1988 aroused public concern about the impacts of increased concentrations of greenhouse gases in the atmosphere. Scientists agree that higher concentrations will result in higher temperatures, climate changes, higher sea levels, and economic damage. However, scientists do not agree on the magnitude or timing of the changes.

During the next 100 years, the level of emissions of carbon dioxide will depend on world population, per capita GNP, energy efficiency, and energy supply. World population and per capita GNP are expected to increase. Reduction of future emissions of carbon dioxide requires increases in energy efficiency and increases in the use of alternative energy sources (nuclear power, biomass, and advanced sources [solar and fusion]). Reforestation and the substitution of natural gas for coal can make a small reduction in future emissions.

Research sponsored by U.S. DOE Office of Fossil Energy and Office of Planning and Environment.

3.104

THE REPLACEMENT COST INTEGRATION PROGRAM USER'S GUIDE

D. B. Reister

(Abstract of ORNL/TM-11124, March 1989)

The Oak Ridge National Laboratory and subcontractor ICF-Lewin Energy have developed a set of computer models to forecast the replacement cost of domestic crude oil. The REPCO model forecasts the replacement cost in the lower 48 states. The Arctic Economics Model forecasts the replacement cost in Alaska. The two models of the replacement cost system forecast domestic oil supply curves (schedules of the amount of oil available at various costs). The Replacement Cost Integration Program (RCIP)

integrates the output from the two models to forecast the annual discoveries and production of domestic crude oil.

RCIP is a user-friendly menu-driven program that is designed to run on an IBM-PC. RCIP allows the user to conveniently edit the input parameters, to calculate the results, and to display the output. In addition, the user can easily store a scenario on a disk and retrieve a scenario from the disk. The built-in output editor allows the user to choose an aggregation scheme for the regional results and retrieve a scenario for comparison. The output can be directed to a file or to the screen.

This user's guide for RCIP contains detailed directions for installing and operating RCIP. The guide discusses all of the parameters on the input screens of the model. The format and units of the output files of the model are reviewed in Appendix B.

Research sponsored by U.S. DOE Office of Fossil Energy and Office of Oil, Gas, Shale, and Special Technology Gas.

3.105

REPLACEMENT COST INTEGRATION PROGRAM MODEL DESCRIPTION

D. B. Reister

(Abstract of ORNL/TM-11132, March 1989)

The Oak Ridge National Laboratory and subcontractor ICF-Lewin Energy have developed a set of computer models to forecast the replacement cost of domestic crude oil. The Replacement Cost model forecasts the replacement cost in the lower 48 states; the Arctic Economics Model forecasts the replacement cost in Alaska. The two models of the replacement cost system forecast domestic oil supply curves (schedules of the amount of oil available at various costs). The Replacement Cost Integration Program (RCIP) integrates the output from the two models to forecast the annual discoveries and production of domestic crude oil.

RCIP is a user-friendly, menu-driven program designed to run on an IBM personal computer. RCIP allows the user to conveniently edit the input parameters, to calculate the results, and to display the output. In addition, the user can easily store a scenario on a disk and retrieve a scenario from the disk. The built-in output editor allows the user to choose an aggregation scheme

for the regional results and retrieve a scenario for comparison. The output can be directed to a file or to the screen.

This Model Description provides an introduction to the models and presents a mathematical description of the oil supply model and of the drilling model.

Research sponsored by U.S. DOE Office of Fossil Energy and Office of Planning and Environment.

3.106

REPLACEMENT COST INTEGRATION PROGRAM MODEL OVERVIEW

D. B. Reister

(Abstract of ORNL/TM-11042, February 1989)

The Oak Ridge National Laboratory and its subcontractor ICF-Lewin Energy have developed a set of computer models to forecast the replacement cost of crude oil. The REPCO model forecasts the replacement cost in the lower 48 states. The Arctic Economics Model forecasts the replacement cost in Alaska. The two models of the replacement cost system forecast domestic oil supply curves (schedules of the amount of oil available at various costs). The Replacement Cost Integration Program (RCIP) integrates the output from the two models to forecast the annual discoveries and production of domestic crude oil.

RCIP is a user-friendly menu-driven program that is designed to run on an IBM-PC. RCIP allows the user to conveniently edit the input parameters, to calculate the results, and to display the output. In addition, the user can easily store a scenario on a disk and retrieve a scenario from the disk. The built-in output editor allows the user to choose an aggregation scheme for the regional results and retrieve a scenario for comparison. The output can be directed to a file or to the screen.

This Model Overview provides an introduction to the models and presents some typical results.

Research sponsored by U.S. DOE Office of Fossil Energy and Office of Oil, Gas, Shale, and Special Technology Gas.

3.107

VALIDATION OF THE REPLACEMENT COST INTEGRATION PROGRAM

D. B. Reister D. S. Christiansen*

(Abstract of ORNL/TM-11046, February 1989)

The Oak Ridge National Laboratory and its subcontractor ICF-Lewin Energy have developed a set of computer models to forecast the replacement cost of domestic crude oil. The model REPCO forecasts the replacement cost in the lower 48 states. The Arctic Economics Model (AEM) forecasts the replacement cost in Alaska. The two models of the replacement cost system forecast domestic oil supply curves (schedules of the amount of oil available at various prices). The Replacement Cost Integration Program (RCIP) integrates the output from the two models to forecast the annual discoveries and production of domestic crude oil.

RCIP has been developed over several years. The most recent version was completed and delivered to DOE in January 1988. In the summer of 1987, a project was begun to validate RCIP. To validate RCIP, a historical data base was developed for the period 1970-1986, and the data base was used to estimate the parameters in the drilling model and to estimate regional finding rates. The data base includes regional data on drilling footage for exploratory and developmental wells, on additions to proved reserves from exploratory and developmental activities, and on production.

Research sponsored by U.S. DOE Office of Planning and Environment.

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3.108

THE REPLACEMENT COST INTEGRATION PROGRAM, AN ENGINEERING-ECONOMIC MODEL OF OIL SUPPLY

D. B. Reister D. S. Christiansen*

[Abstract of paper to be presented at the IAEE 1989 North American Conference, Los Angeles, CA, October 16-18, 1989; Proc. pp. 89-98 (1989)]

The Replacement Cost Integration Program (RCIP) forecasts the annual additions to proven reserves and production of domestic crude oil.

The inputs to RCIP include parameters (discount rate, tax rate, and supply elasticity), expected oil prices, and process model output. The process model output consists of capital costs, operating costs, and production levels for 31 regions. For each region and year, RCIP calculates expected profits and forecasts the level of reserve additions. Two production profiles relate reserve additions to future oil production. The parameters in the model were estimated using data for 1970 to 1986. Results are presented for two sets of prices: high and low. For the period from 1987 to 2020, the cumulative production of oil increases by 64 percent from the low case to the high case, while the cumulative additions to proven reserves increase by more than a factor of three.

Research sponsored by U.S. DOE Fossil Energy Office of Oil, Gas, Shale, and Special Technology Gas.

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3.109

THE RAMS COAL MODEL: VOLUME I — MODEL OVERVIEW VOLUME II — USER'S GUIDE VOLUME III — MODEL DESCRIPTION

**D. B. Reister J. V. Conopask*
P. E. Muhlmeister***

(Abstract of ORNL/TM-10686/V1, ORNL/TM-10686/V2, and ORNL/TM-10686/V3, February 1988)

The RAMS coal model was developed to aid the planning functions of the Office of Fossil Energy of the Department of Energy. The model was designed to simulate the market penetration of processes that use coal to produce liquid fuels. To simulate market penetration, we assume that the least cost process will have the largest share of the market. To evaluate the future income and costs for a process, we need to estimate the prices of all of the inputs and outputs for all of the coal processes and for all of the competing processes. After a literature review, we identified 26 types of energy, by-products, and factors of production that are potential inputs or outputs for a process. The coal model simulates the supply and demand for the 26 types of goods.

The coal model input-output (I-O) structure has 13 sectors to produce the first 24 goods (the last 2 factors, labor and capital, are exogenous inputs). The first 10 sectors produce the first 10 goods, which are either primary or secondary forms of energy. Sector 11, the liquid fuels sec-

tor, produces refined petroleum products and by-products, the goods from 11 to 23. Sector 12 produces good 24, materials. The final sector, sector 13, is the trade sector.

Volume I provides an overview of the RAMS coal model. After an introduction to the RAMS family of models, we discuss some of the key design issues for the coal model. To demonstrate the flexibility of the model, we adjusted the parameters and input variables of the model in an attempt to reproduce the base case scenario published in the most recent National Energy Policy Plan (NEPP). The results demonstrated that the model can create a scenario that is quite similar to the NEPP scenario.

Volume II is a user's guide for the RAMS coal model. After a discussion of how to install and operate the model, the report provides a guided tour of the five input data sets and the six output data sets. One of the input data sets can be edited using LOTUS 1-2-3. The model has a menu-driven

output editor that displays graphical output for all of the variables in the model.

Volume III presents the equations for the core model and for all of the existing satellite models. The supply models (oil, gas, and coal) calculate the I-O coefficients for the first 6 sectors. The liquid fuels model calculates the coefficients for sector 11. The end-use model calculates the coefficients for sector 12. The remaining sectors (7 to 10) have fixed coefficients. The overall architecture of RAMSCOAL features a core model and a family of satellite models. The core model is a general equilibrium model of the supply and demand for the 23 types of energy and by-products. Given I-O coefficients for each of the first 12 sectors and the levels of imports and exports, the core model balances supply and demand and forecasts prices and quantity of production for the 23 types of energy and by-products. The I-O coefficients for each sector are forecast by the satellite models.

Research sponsored by U.S. DOE Office of Fossil Energy.

* Applied Management Sciences, Inc., Oak Ridge, TN.

DOSIMETRY

3.110

PRESSURE VESSEL FLUENCE ANALYSIS AND NEUTRON DOSIMETRY

F. B. K. Kam* R. E. Maerker
M. L. Williams† F. W. Stallmann*

[Abstract of ORNL/TM-10651 (NUREG/CR-5049), December 1987]

A review of the various methodologies used by industries and research institutes for reactor pressure vessel (RPV) fluence determination shows that most organizations employ an analysis sequence consisting of three steps. These include transport calculations, dosimetry measurements, and a statistical procedure to combine the calculations and measurements to arrive at a fluence value which has a smaller uncertainty than the original calculations. An accurate determination of damage fluence accumulated by the RPV as a function of space and time is essential in order to ensure the vessel integrity for both pressurized thermal shock transients and end-of-life considerations. The desired accuracy for neutron expo-

sure parameters such as displacements per atom or neutron fluence ($E > 1.0$ MeV) is of the order of $\pm 10\%$ to $\pm 15\%$ (1σ). These types of accuracies can only be obtained realistically by validation of the entire analysis sequence in benchmark experiments. This report identifies a standardized procedure based on benchmarked calculations, data, and dosimetry measurements, which could be used by organizations performing RPV fluence determinations. Another purpose of this report is to provide supporting documentation for any proposed regulatory guide on this subject.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

* Research Reactors Division.

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3.111

ANALYSIS OF THE VENUS-3 EXPERIMENTS

R. E. Maerker

(Abstract of ORNL/TM-11106, NUREG/CR-5338, August 1989)

The results of applying a hybrid superposition-synthesis calculational method to a mockup of a three-dimensional geometry involving a partial length shield assembly (PLSA) at the VENUS-3 facility in Mol, Belgium, are described. Comparisons of transport calculations using the method and many measurements involving nickel, indium, and aluminum dosimeters indicate agreement generally to within five percent if effects of inaccuracies in the dosimeter cross sections are minimized and proper orientation of the coordinate system used in the synthesis procedure is observed. These conclusions bode well for the success of this method in solving neutron transport problems involving the use of PLSAs in light water reactors to reduce core leakage in pressurized thermal shock programs.

A second report describing the experimental details of the measurements will serve as companion documentation to this one and will be furnished by the Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucléaire, Mol, Belgium.

Research sponsored by Division of Engineering, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission.

3.112

THE LEPRICON CODE SYSTEM: CONSOLIDATION OF TRANSPORT ANALYTICAL AND UNFOLDING PROCEDURES IN LWR PRESSURE VESSEL DOSIMETRY

R. E. Maerker

(Abstract of *Trans. Am. Nucl. Soc.* 57, 225 (1988))

The Least-Squares Electric Power Research Institute Consolidation (LEPRICON) program code system has been developed over the past 10 years to provide a complete analysis of light water reactor (LWR) pressure vessel dosimetry. The system incorporates nine modules. All but one of the

modules treat various aspects of neutron transport from the core through the reactor internals to dosimetry locations in the downcomer and/or reactor cavity regions and to critical fluence locations in the pressure vessel. The LEPRICON adjustment module, on the other hand, performs a state-of-the-art least-squares analysis of the results from the transport modules, a procedure often referred to as spectral unfolding or the combining of integral and differential data. In terms of development, the adjustment module alone required ~70% of the total effort. The results from the LEPRICON system thus represent prior and adjusted fluences in each of 38 groups from 0.1 to 20 MeV, along with their corresponding standard deviations, at critical locations in the pressure vessel.

Results of applying the LEPRICON system to two different power reactors have appeared in the literature, and the conclusion was reached in both cases that the accumulated pressure vessel fluences could be determined to within ~10%. One of the major discoveries was a consistent adjustment of ~8% downward in the iron inelastic cross section in the 3- to 8-MeV region. An update to the Mod-3 evaluation of ENDF/B-V natural iron, spurred by these LEPRICON findings as well as from other sources, has recently been performed, and the resulting improvements in the agreement between calculations and measurements for all 37 benchmarks involving iron penetration, as well as in the above reactor analyses, provide strong evidence for the superiority of this new evaluation and the consistency of the LEPRICON adjustment procedure. As a consequence, this set has been added to the ELXSIR library for future calculations.

In conclusion, the complete LEPRICON methodology provides a comprehensive and accurate analysis of LWR dosimetry and, as a result, has been recommended as serving the needs of the U.S. Nuclear Regulatory Commission for extended pressure vessel lifetime monitoring.

Research sponsored by U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research.

3.113

BENCHMARK VERIFICATION OF A METHOD FOR CALCULATING LEAKAGE FROM PLSA MODIFIED CORES

R. E. Maerker P. D'hondt*
L. Leenders* A. Fabry*

[Abstract of *Trans. Am. Nucl. Soc.* 60, 545 (1989)]

The results of applying a hybrid superposition-synthesis calculational method to a mockup of a three-dimensional geometry involving a partial length shield assembly (PLSA) at the VENUS-3 facility in Mol, Belgium, are described. Comparisons of transport calculations using the method and many measurements involving nickel, indium, and aluminum dosimeters indicate agreement generally to within five percent if effects of inaccuracies in the dosimeter cross sections are minimized and proper orientation of the coordinate system used in the synthesis procedure is observed. These conclusions bode well for the success of this method in solving neutron transport problems involving the use of PLSAs in light water reactors to reduce core leakage in pressurized thermal shock programs.

Research sponsored by U.S. DOE Office and Nuclear Regulatory Commission.

*SCK/CEN, Mol, Belgium.

3.114

ANALYSIS OF THE VENUS-3 EXPERIMENTS

R. E. Maerker P. D'hondt*
L. Leenders* A. Fabry*

(Abstract of paper to be presented at the Seventh ASTM-EURATOM Symposium on Reactor Dosimetry in Strasbourg, France, August 27-31, 1990)

Over the past several years, plant life extension programs have been implemented in many U.S. plants. One method of pressure vessel (PV) fluence rate reduction being used in several of the older reactors involves partial replacement of the oxide fuel with metallic rods in those peripheral assemblies located at critical azimuths. This substitution extends axially over a region that depends on the individual plant design, but covers the most critical PV weld and plate locations which may

be subject to pressurized thermal shock. In order to analyze the resulting PV dosimetry using these partial length shield assemblies (PLSA), a relatively simple but accurate method needs to be formulated and qualified that treats the axially asymmetric core leakage.

Comparisons of the equivalent fission fluxes involving all the dosimeters indicate agreement generally to within 5% when proper orientation of the coordinate system used in the synthesis procedure is observed. The method is apparently very accurate (i.e., the agreement lies generally within the measurement uncertainties) for detector locations of greatest concern in PLSA geometries. In particular, the agreement behind the PLSA is comparable to that behind an unmodified assembly. In conclusion, the success of the proposed method bodes well for the accuracy of future analyses of on-line plants using PLSAs.

Research sponsored by U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research and U.S. Department of Energy.

*SCK/CEN, Mol, Belgium.

HUMAN-COMPUTER INTERACTIONS

3.115

HUMAN FACTORS IN THE NAVAL AIR SYSTEMS COMMAND: COMPUTER-BASED TRAINING

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M. Terranova W. J. Walker‡
D. T. Jones‡

[Abstract of paper presented at the Human Factors Society
32nd Annual Meeting, Anaheim, CA, October 24-28, 1988;
Proc. Vol. 2, pp. 1095-1099 (1988)]

Military standards applied to the private sector contracts have a substantial effect on the quality of Computer Based Training (CBT) systems procured for the Naval Air Systems Command. This study evaluated standards regulating the following areas in CBT development and procurement: interactive training systems, cognitive task analysis, and CBT hardware. The objective was to develop some high-level recommendations for evolving standards that will govern the next generation of CBT systems. One of the key recommendations is that there be an integration of the instructional systems development, the human factors engineering, and the software development standards. Recommendations were also made for task analysis and CBT hardware standards. Recommendations were also made for task analysis and CBT hardware standards.

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3.116

TEAMWORK AND DATA DELIVERABLES: A MAP TO SOFTWARE AND TRAINING DESIGN INTEGRATION

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S. Webster‡

[Abstract of paper to be presented at the Inter-
service/Industry Training Systems Conference, Fort Worth,
TX, November 16, 1989]

A team of training technologists has developed an acquisition structure to help the Navy Airborne Weapons Training Program in managing the development of desk-top training systems by the private sector. The goal of the structure is to meet the special requirements of the users: NAVAIR managers, Navy trainers, and the fleet. Developing interactive training systems requires the application of three engineering disciplines: software engineering, instructional design, and human factors engineering. Each discipline has an associated set of military standards and Data Item Descriptions (DIDs), but these usually have not been applied together in the acquisition of training systems. The cost involved in using three sets of standards and DIDs becomes prohibitive, especially for procuring desk-top computer-based systems. The alignment of the three development processes is not specified by existing guidelines. This paper offers a way to specify the objectives of training and to ensure that they are met during the software development process; it also suggests how to integrate human factors engineering up-front at an affordable level that includes the recognition of cognitive and effective factors in the training process. Ultimately, it specifies software documentation and development that should lead to generic programs that can be maintained and supported by the procuring organization. The acquisition structure is summarized in a matrix that aligns the review of documentation supporting each engineering process in an integrated development cycle. The matrix is a map of the planning, analysis, design, and development phases that coordinates the data deliverables for training, human

factors, and software development. Only through the successful integration of the three disciplines—software engineering, instructional design, and human factors engineering—can future training goals be reached.

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3.117

A PART-TASK TRAINER IN THE NAVAL AIR SYSTEMS COMMAND

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[Abstract of paper to be presented at the American Nuclear Society Topical Meeting on Advances in Human Factors Research on Man/Computer Interactions: Nuclear and Beyond, Nashville, TN, June 10–14, 1990]

Military preparedness is becoming more dependent upon human-computer interaction. Interactive computer systems are playing major roles in training the military. Simulation of the total system, as physically realistic as budgets allow, has been the military's approach to training. Several factors now lead to consideration of part-task trainers for single, complicated tasks. One factor is the difficulty of maintaining simultaneous delivery of the weapons system and the complete simulator. Another is the need for on-the-job refresher training in distant fields of operation. Because part-task trainers are in a sense modules, they increase the maintainability and adaptability of the total system and the acceptability of partial simulation when operational systems are very complex. However, part-task trainers do have drawbacks. Separating skills in part-task trainers may give the impression of simple tasks and may not portray the complexity of military operations. User acceptability and training effectiveness are subject to question with partial simulation. "How real is real enough?" and "How do we identify the essential elements of a task?" have no easy answers.

The introduction of new weapons on an existing aircraft offers a special case where part-task trainers may be appropriate. The configuration of shore-based aircraft simulators may not include the new weapon in time for initial training, or the weapon might be deployed to the fleet before the

aircrews are scheduled for shore-based simulator training. Because the trainees are already expert pilots, they have no delusions about the complexity of their environment and should be able to accept a trainer that covers only tasks new to total system operation. The Naval Air Systems Command has therefore developed a part-task trainer for a new airborne weapon, the Stand-off Land Attack Missile. The trainer has been deployed to the fleet and is slated for shore-based training. This provides an opportunity to use instructional design and human factors methodology to field-test the effectiveness and acceptability of part-task trainers. The Department of Energy's Oak Ridge training technology team will gather data that evaluates the trainer's instructional design and acceptability features. This evaluation will provide criteria for future decisions regarding computer-aided training options for complex tasks.

Research sponsored by U.S. Department of Energy.

*Data Systems Research and Development Division.

3.118

DYNAMIC ALLOCATION OF RESPONSIBILITY BETWEEN OPERATORS WITH DIFFERENT MODELS OF SYSTEM INFORMATION USING COMPUTER-MEDIATED COMMUNICATION

M. Terranova

[Abstract of Ph.D. Thesis, Old Dominion University, Norfolk, VI, Dissertations Abstracts International (in press)]

This research focused on the performance of human operators in systems with high levels of automation. In these systems the use of more than one operator has the potential to optimize the contribution of human performance. In this study, specific consideration was given to different models of system representations and operator communication requirements. The results demonstrated that the communication of the operators is vital to this team effort.

An experimental design was utilized which allowed dynamic control between two human operators in a process control simulation. Control and failure detection responsibilities were shared between the operators using computer-mediated communication. Each of the operators, in teams composed of a primary and support operator, was

provided with either the same or different representations of the process. The results demonstrated a positive relationship between the ability of the teams to stabilize the process and the amount of communication they exchanged. Communication dropped significantly during sessions that included system failures. When failures were present the performance of the teams in optimizing the system and minimizing system takeovers was significantly degraded. The drop in communication was indicative of the increased cognitive workload of diagnosing failures. Although there were no differences in the ability of the teams to control the process or detect failures based on the system representations that the operators used, the way in which they utilized information did vary with this factor. This information utilization was significantly better for the teams composed of a primary operator utilizing an alphanumeric representation and a support operator utilizing a graphic representation. Comparisons were made with similar research which used individuals rather than teams (Coury & Pietras, 1986). These comparisons revealed that the teams in the present study were not as effective in optimizing the process or detecting failures. These differences may be attributed either to population differences, workload requirements of team communication and coordination, or actual differences in the performance of teams versus individuals.

Research sponsored by U.S. Department of Energy.

3.119

COGNITIVE TASK ANALYSIS: TECHNIQUES APPLIED TO AIRBORNE WEAPONS TRAINING

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C. E. Snyder† I. E. Treitler‡

(Abstract of paper to be presented at the 33rd Annual Human Factors Society Meeting, Denver, CO, October 16-20, 1989)

This is an introduction to cognitive task analysis as it may be used in Naval Air Systems Command (NAVAIR) training development. The focus of a cognitive task analysis is human knowledge, and its methods of analysis are those developed by cognitive psychologists. This paper explains the role that cognitive task analysis and presents the findings from a preliminary cognitive tasks analysis of airborne weapons operators. Cognitive task analysis is a collection of powerful techniques that are quantitative, computational, and rigorous. The techniques are currently now in wide use in the training community, so examples of this methodology are presented along with the results.

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COGNITIVE MODELING/OPERATOR ROLES

3.120

FEASIBILITY OF QUANTITATIVE PERFORMANCE MEASURES FOR EVALUATING NUCLEAR POWER PLANT OPERATORS

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P. A. Krois†

(Abstract of paper presented at the 8th Symposium on the Training of Nuclear Facility Personnel, Gatlinburg, TN, April 24-27, 1989; Proc. V.A.5.1-V.A.5.19 (April 1989))

A more valid measure of team performance in nuclear power plants is needed. A study is described which was oriented towards evaluating the feasibility of synthesizing performance measures by deriving measures for crews responding to an off-normal event in a full-scope simulator.

The thesis was that performance assessment is based on the subjective judgment of training instructors. The procedure used to synthesize the performance measure consisted of: identification of the factors believed to be important to performance assessment, development of example crew performances and ratings on each by instructors, and derivation of the measure by capturing the instructors' assessment rules. A performance measure was derived which explains nearly all of the variance of the instructors' team performance assessments. There is reason to believe that this method of synthesizing measures can be applied to other events.

Research sponsored by U.S. Department of Energy and U.S. Nuclear Regulatory Commission.

*Performance Measurement Associates, Reston, VA.

†Computer Technology Associates, Colorado Springs, CO.

3.121

OPERATOR ROLE DEFINITION AND HUMAN SYSTEM INTEGRATION

H. E. Knee J. C. Schryver

[Abstract of paper presented at the 7th Power Plant Dynamics, Control and Testing Symposium, Knoxville, TN, May 15-17, 1989; Proc. p. 5.01 (May 1989)]

This paper discusses operator role definition and human-system integration from a perspective of systems engineering and allocation of functions. Current and traditional allocation of tasks/functions can no longer be applied to systems that are significantly more sophisticated and dynamic than current system designs. For such advanced and automated designs, explicit attention must be given to the role of the operator in order to facilitate efficient system performance. Furthermore, such systems will include intelligent automated systems which will support the cognitive activities of the operator. If such systems share responsibility and control with the human operator, these computer-based assistants/associates should be viewed as intelligent team members. As such, factors such as trust, intentions, and expectancies among team members must be considered by the systems designer. Such design considerations are discussed in this paper.

This paper also discusses the area of dynamic allocation of functions and the need for models of the human operator in support of machine forecast of human performance. The Integrated Reactor Operator/System (INTEROPS) model is discussed as an example of a cognitive model capable of functioning beyond a rule-based behavioral structure.

Research sponsored by U.S. DOE Office of Technology Support Programs.

3.122

AN OPERATOR MODEL-BASED FILTERING SCHEME

R. S. Sawhney* J. C. Schryver

(Abstract of paper to be presented at the American Nuclear Society Topical Meeting on Advances in Human Factors Research on Man/Computer Interactions: Nuclear and Beyond, Nashville, TN, June 19-14, 1990)

This paper presents a LISP-based diagnostic model for off-normal events developed at Oak Ridge National Laboratory (ORNL) under the Advanced Controls Program (ACTO). Although the diagnostic model was intended to serve as an embedded module of a cognitive model of the human operator, one application of this model could be to assist control room operators in correctly responding to off-normal events by providing a rapid and accurate assessment of alarm patterns and parameter trends. The sequential filter model is comprised of two distinct subcomponents — an alarm analysis followed by an analysis of plant signals. During the alarm analysis phase, patterns of annunciated alarms are evaluated to generate hypotheses of possible initiating events in order of likelihood of occurrence. The parameter analysis further evaluates each member of the hypothesis with respect to the current trends of state variables to validate/reject (in the form of increased/decreased certainty factor) the given hypothesis. Updated analysis also incorporates old hypotheses into the first stage filter.

The model is unique in the sense that it incorporates information not utilized by other models in diagnosing initiating events for off-normal scenarios. In particular, there are three types of information which hold the opportunity to improve the prioritization of hypotheses. First, the model has the ability to perform alarm-to-alarm mapping to modify alarm confidence factors based on expectations derived from the annunciated alarm patterns. The basis for this mapping is a correlation matrix that specifies dominant correlations between an annunciated alarm and other relevant alarms. Second, the model performs an unannunciated alarm analysis to verify and modify the results of the annunciated alarm analysis. The assumption is that there is valuable information content contained in unannunciated alarms that may be useful in generating more accurate hypotheses. Last, a parameter analysis procedure is developed that incorporates the distance between expected

and observed parameter trends to modify the confidence factors. The basis for the distance metric is a set of trend tree structures developed for each parameter/initiating event pair.

This model is an improvement over the knowledge-based component of the Integrated Reactor Operator/System (INTEROPS) model also developed at ORNL. The new diagnostic model is a more flexible model which integrates the alarm analysis and the parameter analysis into a single diagnostic model.

Research sponsored by U.S. DOE Office of Technology Support Programs.

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3.123

A HYPOTHESIS GENERATION MODEL OF INITIATING EVENTS FOR NUCLEAR POWER PLANT OPERATORS

R. S. Sawhney* J. C. Schryver
H. E. Knee H. L. Dodds*

[Abstract of Trans. Am. Nucl. Soc. 60, 179 (1989)]

The goal of existing alarm filtering models is to provide the operator with the most accurate assessment of patterns of annunciated alarms. Some models are based on event-tree analysis such as DuPont's Diagnosis of Multiple Alarms (DMA). Other models focus on improving hypothesis generation by deemphasizing alarms not relevant to the current plant scenario. Many such models utilize the Alarm Filtering System (AFS) as a basis of dynamic prioritization. The Lisp-based alarm analysis model presented here was developed for the Advanced Controls Program (ACTO) at Oak Ridge National Laboratory (ORNL) to dynamically prioritize hypotheses via an AFS by incorporating an unannunciated alarm analysis with other plant-based concepts.

The objective of this effort is to develop an alarm analysis model that would allow greater flexibility and more accurate hypothesis generation than the prototype fault diagnosis model utilized in the Integrated Reactor Operator/System Model (INTEROPS). INTEROPS is a time-based predictive model of the nuclear power plant operator which utilizes alarm information in a manner similar to the human operator. This is achieved by recoding the knowledge base from the PC-

based expert system shell to a common Lisp structure providing the ability to easily modify both the manner in which the knowledge is structured as well as the logic by which the program performs fault diagnosis. The Lisp-based alarm analysis logic incorporates (a) alarm-to-alarm domain mapping and (b) utilizes information from alarms that have not annunciated.

Research sponsored by U.S. DOE Office of Technology Support Programs.

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3.124

OPERATOR MODEL-BASED DESIGN AND EVALUATION OF ADVANCED SYSTEMS: COMPUTATIONAL MODELS

J. C. Schryver

[Abstract of paper presented at the 1988 IEEE Fourth Conference on Human Factors and Power Plants, Monterey, CA, June 5-9, 1988; Proc. pp. 121-127 (1988)]

A multi-level operator modeling effort is recommended to provide broad support for integrated design of advanced control and protection systems for new nuclear power plants (NPP). A computational model is described which accounts for the cognitive activities of the operator by combining the advantages of network simulation and knowledge-based simulation. The Integrated Reactor Operator/System (INTEROPS) model is a time-based simulation model which can be coupled with, and control, a thermal-hydraulics model of a nuclear power plant. The INTEROPS model can provide fine-grained evaluation of allocation of functions during the iterative design phase of advanced systems.

Research sponsored by U.S. DOE Office of Technology Support Programs.

3.125

OPERATOR MODEL-BASED DESIGN AND EVALUATION OF ADVANCED SYSTEMS: CONCEPTUAL MODELS

J. C. Schryver

[Abstract of paper presented at the 1988 IEEE Fourth Conference on Human Factors and Power Plants, Monterey, CA, June 5-9, 1988; Proc. pp. 115-120 (1988)]

A multi-level operator modeling approach is recommended to provide broad support for the integrated design of advanced control and protection systems for new nuclear power plants. Preliminary design should address the symbiosis of automated

systems and human operator by giving careful attention to the roles assigned to these two system elements. A conceptual model of the operator role is developed in the context of a command-control-communication problem. According to this approach, joint responsibility can be realized in at least two ways: sharing or allocation. The inherent stabilities of different regions of the operator role space are considered. It is conjectured that the "supervisor" role may prove to be less effective than an "equal partner" role, because the latter maximizes the degree of engagement for the operator.

Research sponsored by U.S. DOE Office of Technology Support Programs.

USAGE OF ADVANCED INSTRUMENTATION AND CONTROLS — THE NUCLEAR INDUSTRY

3.126

DIGITAL INSTRUMENTATION AND INTERACTIVE COMPUTER SYSTEMS: A SURVEY OF THE USE OF ADVANCED TECHNOLOGY IN THE NUCLEAR INDUSTRY

R. J. Carter

(Abstract of paper presented at the American Institute of Chemical Engineers Summer National Meeting, Philadelphia, PA, August 20-23, 1989)

Similar to the chemical industry, the nuclear utilities have utilized analog instrumentation and controls (I&C) in their power plants since the first facility went on-line in the late 1950's. Unlike most of the chemical industry, however, the nuclear utilities have begun to make the transition to digital I&C. This is due in part to: 1) analog components and systems are becoming obsolete and unavailable, and 2) it seems easier to handle the multiple (and sometimes conflicting) goals of efficiency, reliability, economic operation, and safety during the operation of a nuclear power plant with digital technology.

A survey of the use of advanced I&C in the nuclear industry was conducted by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission (NRC). The purpose of the survey was to identify the current, planned, and potential future uses of digital and interactive computer systems in power plant control rooms and

technical support centers. The survey was conducted at the U.S. and Canadian nuclear vendors and six utilities who have begun to use advanced technology/systems. The survey investigated such topics as: the utilization of computers, digital I&C, artificial intelligence, and expert systems; computer-generated displays; cathode-ray tube and gas plasma displays; software validation and verification; usefulness and operability; and human factors. The conference paper and the presentation describe the survey and results therefrom. The viewpoints and opinions expressed are those of the author and do not necessarily reflect those of the U.S. NRC.

Research sponsored by NRC Office of Nuclear Regulatory Research and U.S. Department of Energy.

3.127

HUMAN FACTORS ASPECTS OF ADVANCED INSTRUMENTATION IN THE NUCLEAR INDUSTRY

R. J. Carter

[Abstract of paper presented at the 7th Power Plant Dynamics, Control and Testing Symposium, Knoxville, TN, May 15-17, 1989; Proc. pp. 14.01-14.12 (May 1989)]

The use of advanced/digital instrumentation systems in the nuclear power industry is the wave of the future. These systems will probably be utilized in the life extension of plants. It has been

demonstrated in other industries that digital instrumentation provides almost error-free performance that is three to four orders of magnitude better than analog components performing the same function. With the increase in sophistication in the operation of modern nuclear power plants that is needed to handle the multiple (and sometimes conflicting) goals of efficiency, reliability, economic operation, and safety, the nuclear industry will be driven to the use of advanced instrumentation.

The point has been reached where the issues in using advanced instrumentation in nuclear power plants are not hardware and software reliability or performance, but rather the interface between the instrumentation system and the human. Unfortunately, until recently the human factors issues had not been identified.

Research sponsored by U.S. Nuclear Regulatory Commission.

3.128

HUMAN FACTORS SURVEY OF ADVANCED INSTRUMENTATION AND CONTROLS

R. J. Carter

(Abstract of paper to be presented at the 17th Water Reactor Safety Information Meeting, Rockville, MD, October 23-25, 1989)

The nuclear power industry has used analog instrumentation and controls (I&C) in their control rooms and technical support centers since the first nuclear power plant went on-line in the late 1950's. Even today the industry, as a whole, has been slow to implement advanced/digital I&C. The utilization of digital I&C appears, however, to be the wave of the future because most of the analog components and systems are becoming obsolete and no longer available. These advanced systems will also probably be utilized in the life extension of nuclear plants. It has been demonstrated in other industries that digital I&C provides almost error-free performance that is three-to-four orders of magnitude better than analog components performing the same function. With the increase in sophistication in the operation of modern nuclear power plants that is needed to handle the multiple (and sometimes conflicting) goals of efficiency, reliability, economic operation, and safety, the nuclear industry will be driven to the use of advanced I&C.

Research sponsored by U.S. Nuclear Regulatory Commission and U.S. DOE.

3.129

HUMAN FACTORS ISSUES RELATED TO EXPERT SYSTEMS FOR ELECTRIC POWER PLANT CONTROL ROOMS

R. J. Carter R. E. Uhrig*

(Abstract of paper presented at the Conference on Expert Systems Applications for the Electric Power Industry, Orlando, FL, June 5-8, 1989)

The primary purpose of expert systems is to represent the knowledge of experts and make the expertise available to the human so that it can contribute to improved performance. In order to achieve this objective, human factors principles must be incorporated into the design. Two surveys oriented towards identifying the human factors issues related to expert systems were conducted. This paper describes the results from those surveys. It discusses the human factors issues under four main categories, the knowledge base of the expert system, the human-expert system interface, organizational support, and related topics (e.g., training, workload, and performance under stress).

Research sponsored by U.S. Department of Energy and Nuclear Regulatory Commission.

*Instrumentation and Controls Division.

HAZARDOUS WASTE MANAGEMENT

3.130

DESIGNING A HAZMAT INCIDENT MANAGEMENT SYSTEM FOR FACILITIES WITH WIDELY VARYING EMERGENCY ORGANIZATION STRUCTURES

R. J. Carter C. E. Easterly*

[Abstract of paper presented at the American Institute of Chemical Engineers' 9th Biennial Hazardous Material Spills Conference, Chicago, IL, May 16-19, 1988; Proc. pp. 589-597 (May 1988)]

Oak Ridge National Laboratory is currently conducting a research program for the United States Air Force, the purpose of which is to assist them in their emergency planning for HAZMAT spills. This paper describes the first two tasks in the program. These tasks are oriented towards: determining the extent of the hazardous materials (HAZMAT) problem and establishing plans directed toward HAZMAT incident management.

Research sponsored by U.S. Air Force.

*Health and Safety Research Division.

3.131

A GENERIC HAZARDOUS WASTE MANAGEMENT TRAINING PROGRAM

R. J. Carter B. Karnofsky*

(Abstract of paper presented at the American Nuclear Society Topical Meeting on Nuclear and Hazardous Waste Management, Pasco, WA, September 11-15, 1988)

The Resource Conservation and Recovery Act (RCRA) is the primary federal law governing the

generation, transportation, and disposal of hazardous waste. All nuclear power facilities have processes which produce waste chemicals that are now regulated under this law and its amendments. Some of the more demanding aspects of the RCRA regulation are the training requirements outlined in title 40 of the Code of Federal Regulations, Section 264.16. This section requires semi-annual training of personnel involved in the use, storage, transport, and disposal of hazardous waste. Because the definition of hazardous waste includes relatively inert materials, this training requirement impacts many of the personnel at a nuclear facility.

Oak Ridge National Laboratory is developing a generic, i.e., applicable to all major commands and installations, three-hour RCRA training program for the United States Air Force which is directed towards people responsible for day-to-day use, storage, transport, and disposal of hazardous materials and wastes, and first-line supervisors of these operations. The program highlights major compliance requirements and chronologically follows a hazardous material from its arrival onbase to its departure through a disposal contract. It focuses on both individual responsibilities and the importance of teamwork. Most of the training program also appears to be applicable to the nuclear power industry.

Research sponsored by U.S. Air Force.

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RELIABILITY

3.132

ASSESSMENT OF CRITICAL
COMPONENT UNAVAILABILITY IN
LIQUID METAL REACTORS

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[Abstract of *Nucl. Tech.* 85, 251 (1989); also *Trans. Am. Nucl. Soc.* 56, 388 (1988)]

Availability information contained within the Centralized Reliability Data Organization (CREDO) liquid-metal reactor (LMR) data base is presented, and the availability critical items lists are developed. Individual components are ranked in prioritized lists from worst to best performers from an availability standpoint. Availability, as used here, is assumed to be an inherent characteristic of the component and is not necessarily assumed to be related to plant operability.

A major observation is that of ~5000 components analyzed at each reactor site, a few components have a much higher unavailability factor than the average. In particular, 15 components contribute 93, 77, and 87% of the total system unavailability for the Experimental Breeder Reactor II, the Fast Flux Test Facility, and the Japanese Experimental Fast Reactor (JOYO), respectively. Critical components common to all three sites are mechanical pumps and electromagnetic pumps. By identifying components in this way, site personnel will be more efficient in their attempts at increasing overall system availability; i.e., attention can be focused on components that have a high contribution to overall system unavailability.

All three sites demonstrate that low maintainability (i.e., long repair times) is about twice as likely to contribute to unavailability of component than unreliability (i.e., high failure rates).

The analyses were conducted using data and information from CREDO, the largest repository of LMR component reliability data in the world. The system is cosponsored by the U.S. Department of Energy and the Power Reactor and Nuclear Fuel Development Corporation of Japan. The CREDO data base contains information on a population of >20,000 components and addresses ~1500 events (i.e., abnormal component occurrences). A conservative estimation is that total

component operating hours approaches 2.2 billion hours.

Research sponsored by U.S. DOE Office of Technology Support Programs and the Power Reactor and Nuclear Fuel Development Corporation of Japan.

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3.133

DEVELOPMENT OF FREEDOM/
CREDO DATA BASE FOR
LMFBR PSA

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(Abstract of paper presented at the IAEA Technical Committee Meeting on Evaluation of Reliability Data Sources, Vienna, Austria, February 1-5, 1988)

A probabilistic safety assessment (PSA) is being performed for the liquid-metal cooled fast breeder reactor (LMFBR), MONJU, which is currently in the construction phase. FBR Reliability Evaluation Database for Operation and Maintenance (FREEDOM) has been developed at the Power Reactor and Nuclear Fuel Development Corporation (PNC) for the collection, storage, maintenance, and evaluation of the data to support the MONJU PSA. The FREEDOM system includes the data contents and structure of the Centralized Reliability Data Organization (CREDO). The CREDO system was initially developed in the United States at Oak Ridge National Laboratory (ORNL), and is jointly sponsored by the U.S. Department of Energy (DOE) and PNC of Japan. Data have been collected from the experimental fast reactor, JOYO, the Fast Flux Test Facility (FFTF), and the Experimental Breeder Reactor-II (EBR-II). In addition, data have also been collected at several important test facilities in the U.S. and Japan.

The utilization of the CREDO database has recently been initiated for the MONJU PSA. This paper describes the structure of the database and the approach of CREDO application to the

LMFBR PSA. For better use of reliability data, the effects of component boundary, component failure modes and failure severity were investigated. A failure trend analysis was performed to examine the applicability of these data to the MONJU PSA. The accumulation of operational experience in LMFBRs and a detailed investigation of the existing reliability, availability, and maintainability (RAM) data would contribute to the reduction of the uncertainty of PSA.

Research sponsored by U.S. DOE Office of Technology Support Programs and the Power Reactor and Nuclear Fuel Development Corp., Tokyo, Japan.

*Power Reactor and Nuclear Fuel Development Corp., Tokyo, Japan.

3.134

INTERACTION OF CREDO WITH THE EBR-II PRA DEVELOPMENT

M. S. Smith W. A. Ragland*

[Abstract of *Trans. Am. Nucl. Soc.* 60, 411 (1989)]

The National Academy of Sciences review of DOE Class 1 reactors recommended that the Experimental Breeder Reactor II (EBR-II), operated by Argonne National Laboratory, develop a level 1 PRA and make provisions for level 2 and level 3 PRAs based on the results of the level 1 PRA. The PRA Analysis Group at ANL will utilize the Centralized Reliability Data Organization (CREDO) at the Oak Ridge National Laboratory to support the PRA data needs. CREDO contains many years of empirical liquid metal reactor component data from EBR-II. As of June 1989, there were over 22,000 components (engineering records) and 1918 event records within the CREDO database, of which 2182 engineering and 417 event records were contributed by EBR-II.

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

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Section 4

NUCLEAR ANALYSIS AND SHIELDING

4.0. INTRODUCTION

D. T. Ingersoll

The Nuclear Analysis and Shielding Section is comprised of four groups whose major research activities include: (1) methods development, analysis, and experiments for fission reactor radiation transport and shielding, (2) methods development and analysis for fission reactor core physics, (3) development of computer methods and models for high-energy radiation and particle transport and detection, and (4) mathematical modeling and computer analysis of ground- and space-based defensive systems. (Note: The Department of Energy has categorized some of the work for the reactor programs as "Applied Technology" so explicit references to this work cannot be included in this report.)

The long-established expertise established in the reactor shielding group continued to draw support from a diversity of projects including: (1) characterization of the neutron fluence at the pressure vessel of the 30-year-old Halden reactor in Norway, (2) prediction of neutron and gamma-ray transport in the beam tubes of the proposed Advanced Neutron Source (ANS), design analysis for the high-temperature gas-cooled reactor program, and (4) prediction of gamma-ray dose rates in a proposed demonstration fuel reprocessing plant. Several neutronics analyses were also performed to support the restart of the ORNL High Flux Isotope Reactor. The joint U.S./Japan program of shielding experiments supporting the liquid-metal-cooled reactor program was mostly idled due to the extended shutdown of the Tower Shielding Facility.

Activities in the newly reestablished reactor physics group focused on core performance and design analyses for the ANS, including control concepts, fuel grading options, and nuclear heating. A new effort was initiated which will include methods development, benchmark analysis, and design methodology verification for the gas-cooled reactor concept for the New Production Reactor program. Also, a novel application of artificial intelligence methodology was used to investigate geometry optimization of the cold source for the ANS.

Projects in the high-energy physics area included further developments and improvements to physics models and nuclear data base for the HETC high-energy radiation and particle transport code. Particular emphasis was given to coordinating specific research, design, fabrication, and testing capabilities at ORNL which could contribute toward the large detector projects associated with the Superconducting Super Collider (SSC) program. A successful proposal was developed to establish at ORNL a specialized center for SSC detector development which will involve the active participation of laboratories and universities in the southeast region of the U.S. The center is expected to provide direct support of at least one SSC detector project, especially for the hadron calorimeter stage of the detector, and basic research support of general high-energy detection systems.

The ORNL Fast Track Program, which was initiated earlier to support the Strategic Defense Initiative (SDI), successfully predicted and demonstrated the performance of ultra-lightweight shields for space-based platforms subjected to hypervelocity projectiles. Related programs under the SDI umbrella included optimization studies for radiation threat shields and the effects of radiation on specific space platform components. Work also continued on the further development of the TORT three-dimensional discrete ordinates code and its application to the dose assessment program for personnel at Hiroshima and Nagasaki. Related work was performed to improve adjoint Monte Carlo methods used to predict the radiation hardness of armored vehicles. New analytic models using coupled nonlinear partial differential equations were developed to describe the behavior of

combative forces. Numerical solutions to the system of equations were used to test and improve the models, which include the effects of spatial troop movement, attrition and reenforcement, battlefield length, etc.

RADIATION TRANSPORT AND PHYSICS FOR FISSION REACTORS

4.1

ARTIFICIAL INTELLIGENCE SEARCH TECHNIQUES FOR OPTIMIZATION OF THE COLD SOURCE GEOMETRY

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 57, 97 (1968)]

We draw an analogy between the problem of optimizing the geometric shape of the cold source and a state space search, then we use a simple artificial intelligence (AI) search technique to determine the optimum cold source shape based on a two-group, r - z diffusion model. We implemented this AI design concept in the computer program AID, which consists of two modules, a physical model module and a search module, which can be independently modified, improved, or made more sophisticated. The physical model equations are solved using a special-purpose two-group, r - z nodal diffusion code. The search module in AID uses a nearest-neighbor strategy; at each level of the search, the search module generates all permissible states from the current state using the production rules, evaluates each one, then compares the resulting cold leakage. If none is larger than the cold leakage of the current state, the search terminates successfully. Otherwise, the state with the largest cold leakage is taken to be the current state and the search proceeds to the next level.

In order to demonstrate the capabilities of this new approach, we obtain optimum cold source shapes on two meshes, with a variety of initial states. The utility of our new approach is underscored by the large improvement in performance of the cold source determined by the nearest-neighbor algorithm whose uncommon shape is practically impossible to foresee as a candidate design based on pure physical and engineering intuition.

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

4.2

A STATE SPACE SEARCH TECHNIQUE FOR OPTIMIZING THE SHAPE OF A COLD NEUTRON SOURCE

Y. Y. Azmy

[Abstract of *Nucl. Sci. Eng.* (in press)]

We develop a novel approach for optimizing the geometrical shape of an object designed to extremize a set of performance criteria, and we apply it to the problem of optimizing the shape of a cold neutron source. First, we draw an analogy between the shape optimization problem and a state space search, which is the fundamental problem in Artificial Intelligence applications. Then, we describe our implementation of this new approach into a computer code, DAIT, in which the physical model is represented by a two-group, r - z geometry nodal diffusion method, and the search is conducted via a truncated breadth-first algorithm. This algorithm reduces to the traditional Nearest Neighbor algorithm if we truncate the search breadth at one. We establish the accuracy of the nodal diffusion method solution on the meshes of interest in this work, then we establish the adequacy of the diffusion approximation itself via comparisons with transport theory solutions. Then, we investigate the dependence of the optimum shape and its value on several physical and search parameters via several numerical experiments. Finally, we show that starting from different initial states, the same final optimum state can be obtained if we increase the search breadth sufficiently.

Research sponsored by Defense Advanced Research Projects Agency and by U.S. DOE Office of Basic Energy Sciences.

4.3

GEOMETRICAL SHAPE OPTIMIZATION OF A COLD NEUTRON SOURCE USING ARTIFICIAL INTELLIGENCE STRATEGIES

Y. Y. Azmy

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 2, pp. 67:1-67:12 (1989)]

A new approach is developed for optimizing the geometrical shape of a cold neutron source to maximize its cold neutron outward leakage. An analogy is drawn between the shape optimization problem and a state space search, which is the fundamental problem in artificial intelligence applications. The new optimization concept is implemented in the computer code DAIT in which the physical model is represented by a two group, r - z geometry nodal diffusion method, and the state space search is conducted via the nearest neighbor algorithm. The accuracy of the nodal diffusion method solution is established on meshes of interest and is shown to behave qualitatively the same as transport theory solutions. The dependence of the optimum shape and its value on several physical and search parameters is examined via numerical experimentation.

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

4.4

A PARALLEL ALGORITHM FOR SOLVING THE MULTIDIMENSIONAL NEUTRON TRANSPORT EQUATION

Y. Y. Azmy

(Abstract of paper presented at the SIAM Conference on Applied Linear Algebra, Minneapolis, MN, July 11-15, 1988)

The standard inner iteration procedure, commonly used to solve the discrete ordinates form of the neutron transport equation, is composed of independent sweeps of the mesh along the various discrete directions. In particular, in the S_n approximation, there are $N \equiv n(n+2)/8$ discrete ordinates per quadrant in angle space, so that for each corner at which faces with vacuum

boundary conditions (i.e., known incoming angular flux) intersect there are N independent processes (sweeps) that can execute simultaneously. Since the decomposition of the iteration process into parallel subprocesses occurs in a natural way, the solution obtained from the parallel algorithm is exactly equivalent to its sequential counterpart. We used this algorithm to solve a simple test problem on the Intel iPSC hypercube using the zeroth and first order nodal transport methods and measured the speedup and efficiency as a function of the various parameters in the problem. Speedups larger than 30 (for 40 independent processes) and efficiencies in excess of 70% were consistently achieved throughout our investigation.

Research sponsored by U.S. Department of Energy and by Defense Advanced Research Projects Agency.

4.5

MULTIDIMENSIONAL NODAL TRANSPORT METHODS FOR MULTIPLE-INSTRUCTION MULTIPLE-DATA, DISTRIBUTED MEMORY MACHINES

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 56, 292 (1988)]

It has become evident in recent years that any significant improvements in the performance of future computers must be rooted in advanced architectures. In this paper we present the implementation of the zeroth and first-order two-dimensional nodal transport methods on the hypercube. Our objective is to study the effect of the various parameters in a simple test problem on speedup and efficiency in order to determine the cases most suitable for solving on a distributed memory (DM) machine, such as the hypercube.

In general, discrete ordinates methods have the potential for coarse-grain parallelization because of the complete independence within each inner iteration between the mesh sweeps in the various distinct discrete directions. The parallel solution strategy for each iteration consisted of simultaneous sweeps of the mesh, in the standard sense, performed by the nodes in a preassigned order (static scheduling).

The main feature of this strategy is the very coarse parallelization achieved. This minimizes the number of messages exchanged between

the independent processes, thus improving the efficiency. However, it also limits the largest number of processes that can be executed simultaneously to a few hundred, far below the potential number of processors on DM machines. Another characteristic of this strategy is the very well balanced computational load.

We solved several test problems with vacuum boundary conditions on all external edges in order to study the effect of several parameters on the speedup and the efficiency. For all cases considered, efficiency decreases monotonically, but is consistently above 70%. Our results indicate that, for the same problem, the lowest efficiency of the first-order method was $\sim 10\%$ higher than that of the zeroth method because the sweeps consume a larger fraction of the total CPU time in the former case. For similar reasons we found that, for a given number of processors, P , doubling the number of mesh cells in each direction slightly improved the efficiency. Also, we found that, for a given P , increasing the number of independent processes by increasing the order of angular quadrature results in a higher efficiency. For similar reasons, one would expect three-dimensional methods for problems with purely vacuum boundary conditions to be more efficient than two-dimensional methods.

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

4.6

ACCURACY OF TRANSPORT CALCULATIONS FOR THE ADVANCED NEUTRON SOURCE

Y. Y. Azmy

[Abstract of *Trans. Am. Nucl. Soc.* 57, 293 (1988)]

Due to the very compact core geometry, high fuel enrichments, and low D_2O moderator/coolant content within the core of the ANS reactor, the thermal flux gradient in the core, as well as the epithermal and fast flux gradients in the large D_2O pool reflector, are extremely large. This raises questions about the adequacy of diffusion calculations for this problem, and also about the accuracy of the DORT transport calculations performed to verify the diffusion calculations; in this paper we consider the latter question.

We have roughly estimated the accuracy of the multiplication factor, the fission source, and pointwise scalar flux, obtained from the transport calculations of the ANS reactor, using as reference the corresponding quantities resulting from k^2 extrapolation of two fine-mesh calculations. Our results indicate that the group scalar flux is inaccurate at locations of very low flux levels. This inaccuracy has almost no effect on the multiplication factor, however, and a relatively small effect on the fission source. These, as well as other integral quantities, such as the heating rates, for example, can be expected to be accurate even on relatively coarse meshes due to the penultimate observation.

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

4.7

COMPARISON OF THE DIFFUSION AND TRANSPORT CALCULATIONS FOR THE ADVANCED NEUTRON SOURCE REACTOR

Y. Y. Azmy F. C. Difilippo

[Abstract of paper presented at the 1988 International Reactor Physics Conference, Jackson Hole, WY, September 18-21, 1988; *Proc. Vol. II*, pp. 183-194 (1988)]

We performed six-group two-dimensional, r - z criticality calculations for a previous candidate design for the Advanced Neutron Source (ANS) reactor using a diffusion theory code (BOLD-VENTURE) and a transport code (DORT). Several quantities of practical interest in the design of the ANS were evaluated from the converged solutions and compared to one another. The relative difference between the diffusion and transport estimates of these quantities was also compared to a recently obtained estimate of the accuracy of the transport calculation itself in order to evaluate the diffusion approximation. Our results confirmed that most diffusion calculated quantities are sufficiently accurate with the error mostly arising from the finite size of the computational cells rather than from the underlying theory.

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

4.8

CONVERGENCE PROPERTIES OF ITERATIVE ALGORITHMS FOR SOLVING THE NODAL DIFFUSION EQUATIONS

Y. Y. Azmy B. L. Kirk

(Abstract of paper to be presented at the International Conference on the Physics of Reactors: Operation, Design, and Computation, Marseille, France, April 23-26, 1990)

A five-point scheme has been derived for the nodal diffusion method in two-dimensional Cartesian geometry. An unaccelerated, iterative procedure based on this scheme was derived and implemented on serial as well as parallel computers. In addition, a partial SOR method was developed and shown to provide significant reduction in the number of iterations required to achieve a converged solution. In this work we present and validate expressions for the spectral radius and the number of iterations required for convergence, as a function of the mesh size for a model problem. Also we present preliminary results for a full SOR method that indicates an even better performance.

Research sponsored by U.S. DOE Office of Magnetic Fusion.

4.9

THREE-DIMENSIONAL CALCULATIONS OF NEUTRON STREAMING IN THE BEAM TUBES OF THE ORNL HFIR REACTOR

R. L. Childs* W. A. Rhoades
L. R. Williams

[Abstract of paper presented at the 7th International Conference on Radiation Shielding, Bournemouth, UK, September 12-16, 1988; Proc. Vol. II, pp. 409-418 (1989)]

The streaming of neutrons through the beam tubes in the High Flux Isotope Reactor at Oak Ridge National Laboratory has resulted in a reduction of the fracture toughness of the reactor vessel. As a result, an evaluation of vessel integrity was undertaken in order to determine if the reactor can be operated again. As a part of this evaluation, three-dimensional neutron transport calculations were performed to obtain fluxes at points of interest in the wall of the vessel. By comparing the calculated and measured activation of dosimetry specimens from the vessel surveillance program, it was determined that the calculated flux shape was satisfactory to transpose the surveillance data to

the locations in the vessel. A bias factor was applied to correct for the average C/E ratio of 0.69.

Research sponsored by U.S. Department of Energy.

*Computing and Telecommunications Division.

4.10

DETERMINATION OF KINETICS PARAMETERS USING STOCHASTIC METHODS IN A ^{252}Cf DRIVEN SYSTEM

F. C. Difilippo

[Abstract of paper in *Noise and Nonlinear Phenomena in Nuclear Systems*, Series B: Physics Vol. 192, pp. 99-106, proceedings of the NATO Advanced Research Workshop, Universidad Politecnica de Valencia, Spain, May 23-27, 1988, J. L. Munoz Cobo and F. C. Difilippo, Eds., Plenum Press, NY (1989)]

Safety analysis and control system design of nuclear systems require the knowledge of neutron kinetics related parameters like effective delayed neutron fraction, neutron lifetime, time between neutron generations and subcriticality margins. Many methods, deterministic and stochastic, are being used, some since the beginning of nuclear power, to measure these important parameters. The method based on the use of the ^{252}Cf neutron source has been under intense study at the Oak Ridge National Laboratory, both experimentally and theoretically, during the last years. The increasing demand for this isotope in industrial and medical applications and new designs of advanced high flux reactors to produce it make the isotope available as neutron source (only few micrograms are necessary). A thin layer of ^{252}Cf is deposited in one of the electrodes of a fission chamber which produces pulses each time the ^{252}Cf disintegrates via α or spontaneous fission decay; the smaller pulses associated with α decay can be easily discriminated with the important result that we know the time when ν_p neutrons are injected into the system (number of neutrons per fission of ^{252}Cf). Thus, a small (few cm^3) and nonintrusive device can be used as a random pulsed neutron source with known natural properties that do not depend on biases associated with more complex interrogating devices like accelerators. This paper presents a general formalism that relates the kinetics parameters with stochastic descriptors that naturally appear because of the random nature of the production and transport of neutrons.

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

4.11

THEORETICAL ANALYSIS OF REACTIVITY MEASUREMENT WITH THE ^{252}Cf SOURCE RATIO METHOD

F. C. Difilippo

[Abstract of International Meeting on Safety Margins in Criticality Safety, San Francisco, CA, November 26-30, 1989; Proc. pp. 16-23 (1989)]

Stochastic descriptors are calculated using the concepts of detector field of view and an equivalent source of noise with results that are compatible with a more basic formalism based on a probabilistic analysis of Markovian processes. The model expansion of the detectors' fields of view are further used to relate reactivities to observables measured with the ^{252}Cf ratio method. Results from the analysis of experiments are shown together with a numerical analysis of spatial effects.

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

4.12

HARMONIC ANALYSIS OF STOCHASTIC DESCRIPTORS AND THE INTERPRETATION OF ^{252}Cf NEUTRON SOURCE EXPERIMENTS

F. C. Difilippo

[Abstract of Nucl. Sci. Eng. (in press)]

The harmonic expansion of the detector field of view in terms of direct and adjoint kinetic eigenfunctions together with the use of modified version of Schottky prescription of the equivalent source of noise make possible the harmonic analysis of stochastic descriptors used in the measurement of kinetic parameters. The results are general in the sense that they do not depend on the approximations of the Boltzmann operator, on the distribution of fissile materials, or on the multiplicity of the neutron source that drives the subcritical system. The results are applied to analyze the particular case of a system driven by a ^{252}Cf source, with the californium deposited in one of the electrodes of a fission chamber, and monitored by two sets of neutron detectors. This analysis is oriented towards the interpretation of experiments to measure reactivities with the stochastic method of the

^{252}Cf source (ratio method). The theory is then used to synthesize stochastic observables using a simple approximation of the Boltzmann operator, i.e., two-point kinetics, which show the general features of the spatial effects observed experimentally.

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

4.13

NEUTRON KINETICS OF HIGH- INTENSE FISSION NEUTRON SOURCES

F. C. Difilippo

(Abstract of paper to be presented at the International Conference on the Physics of Reactors: Operation, Design, and Computation, Marseille, France, April 23-26, 1990)

Fission neutron sources capable of producing thermal neutron flux peaks of the order $10^{20} \text{ m}^{-2} \text{ s}^{-1}$ and releasing low power ($\lesssim 300$ MW) require a small and undermoderated core (core volume $V_c \lesssim 50$ L with heavy water coolant) and very low absorbing reflectors (e.g., D_2O). Consequently, the neutron kinetics of highly intense fission neutron sources have the following characteristic problems: There is production of photodelayed neutrons with associated questions about the transport of γ -rays in a very small core; prompt decay constants α_m can be of the order of precursor decay constants γ , so the usual $1/\nu$ poisoning calculation of α_m , kinetic eigenfunction χ_m and kinetic mean life ℓ_m might not be correct; the kinetic distortion is very intense, and the strong space-dependent neutron spectra raise questions about the validity of point-kinetics models. Furthermore, a general formalism for the calculation of lumped parameters is desirable in order to have an appropriate reference for less accurate models. Time-dependent equations for the vector flux $\psi(\vec{\mu}, t)$, $\vec{\mu} \in [\vec{r}, \vec{v}]$ that make allowance for transport effects of the γ 's that induce photoneutron emission in D_2O were derived.

Assuming there are I delayed neutron groups ($i = 1$ to I) and J photodelayed neutrons groups ($i = I + 1$ to $I + J$), the kernels, K_i are introduced, $K_i(\vec{r}', \vec{r}) = \delta(\vec{r}' - \vec{r})$ for $i \leq I$, whereas the K_i for $i > I$ accounts for the transports of γ 's.

In the context of the kinetics of highly intense neutron sources, the conclusions of this work are the following:

1. Rigorous equations for consistent definitions of kinetic parameters were obtained; they include the transport of γ -rays.
2. The prompt approximation for the calculation of time eigenvalue α is not correct in near-critical cases.
3. Because of the kinetic distortion, there is a large difference between static and kinetic mean lives. The difference increases with sub-criticality.
4. Point kinetics is a reasonable approximation ($\sim 10\%$ error) if proper lumped parameters are used.

The experience provided by the previous results is being used to generate lumped kinetic parameters of the Advanced Neutron Source reactor for use in control-related calculations.

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

4.14

FLATTENING THE POWER DISTRIBUTION OF THE ADVANCED NEUTRON SOURCE REACTOR

F. C. Difilippo

[Abstract of *Trans. Am. Nucl. Soc.* 56, 563 (1988)]

The goal of the advanced neutron source (ANS) project is to design an ultrahigh thermal neutron flux ($\sim 10^{16}/\text{cm}^2\cdot\text{s}$) scattering facility with a reactor as a source of neutrons. Efficient design requires the combination of a low absorbing reflector and a small (relative to the neutron slowing down length) core. The results of this combination are a larger than usual average power density (compared to other high flux reactors) and a highly skewed distribution of the power density if the fuel is uniformly loaded. Both of these characteristics and thermohydraulic limits make necessary the use of some remedial technique to flatten the power distribution. We have developed instead an iterative numerical technique to calculate a fuel distribution that will reduce the power peaking factor at a prescribed time during the life of the core. We have used this numerical technique to calculate a fuel distribution that would flatten the power distribution at the middle of core life of a candidate design for the ANS. The maximum local peak-to-average power

factor at that time is 1.14. At beginning of life it is 1.59 and at end of life it is 1.64. These values should be compared with a value of 3.67 at beginning of life for a uniform loading.

The power distribution as a function of space and time was used to compute thermal-hydraulic parameters. The maximum fuel temperature is $\sim 360^\circ\text{C}$, well below the maximum value of $\sim 385^\circ\text{C}$ specified by the ANS project office.

In conclusion, the procedure developed in this paper to reduce the power peaking factor was successfully applied to the design of the fuel distribution within the ANS reactor core. It provides for automated rigorous, quantitative redistribution of fuel, which should provide convergence to an optimized fuel distribution more rapidly than a qualitative human decision procedure.

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

4.15

REACTOR PHYSICS CALCULATIONS FOR THE CONTROL OF THE ADVANCED NEUTRON SOURCE REACTOR

F. C. Difilippo M. Abu-Shehadeh*
R. B. Perez

[Abstract of paper presented at the 1988 International Reactor Physics Conference, Jackson Hole, WY, September 18-21, 1988; Proc. Vol. II, 195-201 (1988)]

Efficient production of extremely high fluxes requires compact cores with consequent high power densities and initial excess reactivities. Strong space dependent neutron spectras and limited access to the small core are other characteristics that make the design of the control system of these type of facilities an interesting problem. We present calculations of (a) the worths of ^{10}B to reduce the initial excess reactivity, (b) the worth of Hf and B control rods, and (c) the neutron lifetimes, for the case of candidate designs for the Advanced Neutron Source reactor.

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

*University of Tennessee, Knoxville, TN.

4.16

TWO-POINT AND TWO-ENERGY GROUP KINETICS MODEL OF THE ANS REACTOR

F. C. Difilippo M. Abu-Shehadeh*
R. B. Perez

[Abstract of *Trans. Am. Nucl. Soc.* 59, 347 (1988)]

The production of extremely high thermal neutron fluxes ($\sim 10^{20}/\text{m}^2\cdot\text{s}$) with reasonable power levels (~ 300 MW) requires the combination of a very undermoderated core and a low-absorbing moderator/reflector (like D_2O). Candidate designs for the reactor of the advanced neutron source (ANS) project have in common the strong coupling between two neutron fields with very different spectra: predominance of epithermal neutrons in the core and thermal neutrons in the reflector. Because there are large variations of the neutron spectra within a few centimeters in a small core, concerns might arise regarding the validity of the conditions under which the point kinetic approach is valid, i.e., the factorization of the flux as the product of two functions: one depending on phase space $\mu(r,v)$ and the other depending only on the time t . In this paper, we present a two-point (core and reflector) and two-energy group fast and thermal model used to calculate power transients in order to detect conditions under which one-point kinetics is not a valid approximation. The equations for the core were written under the hypothesis that the source of fast neutrons in the core is mainly the fission process and the neutron decay of fission products, i.e., we neglected the fast neutrons coming from the reflector and the photoneutron production inside the core. The balance equations for the reflector state that fast neutrons in the reflector are neutrons that come from the core and photodelayed neutrons produced in the D_2O by the gammas coming from the core and that the thermal neutrons in the reflector come mainly from the moderation process in the reflector; i.e., we neglected the thermal neutrons coming from the core. In summary, the coupling in the fast and thermal groups is produced by neutrons that go mainly from the core to the reflector and from the reflector to the core, respectively. The model was applied to compute transients corresponding to practical problems of start-up: The reactor is critical and in equilibrium for $t \leq 0$; for $t > 0$ a positive reactivity is inserted to produce a fast and monotonic rise in

power without overshoot. This is accomplished by the following reactivity profile: a ramp to a value A between 0 and t_1 , constant A between t_1 and t_2 , and an exponential decay to zero for $t > t_2$.

The results show a systematic dependence of the power profile on the way the change in reactivity is made, especially if the reactivity transient is severe, i.e., as t_2 of A increases. This type of power transient is then sensitive to spatial effects not described by the point kinetics approximation.

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

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4.17

RADIATION TRANSPORT CALCULATIONS FOR THE ANS BEAM TUBES

W. W. Engle, Jr. R. A. Lillie
C. O. Slater

[Abstract of *Trans. Am. Nucl. Soc.* 57, 294 (1988)]

The Advanced Neutron Source (ANS) facility will incorporate a large number of both radial and no-line-of-sight (NLS) beam tubes to provide very large thermal neutron fluxes to experimental facilities. Coupled two- and three-dimensional radiation transport calculations were performed to obtain thermal and fast (damage) neutron and gamma-ray scalar fluxes in these beam tubes to allow comparison of the ANS single- and split-core designs. For experimental locations far from the reactor cores, angular flux data are required; however, for close-in experimental locations, the scalar fluxes within each beam tube provide a credible estimate of the various signal to noise ratios. The ratios of the thermal to fast scalar neutron fluxes (scalar neutron fluxes below and above 3.05 eV) were found to be greater for the NLS beam tubes for both core designs since these tubes do not "view" either core; and for both the radial and NLS tubes, the thermal to fast ratios were found to be greater at all distances from the beam tube entrances and increase much more rapidly with increasing distance for the split-core design. Very little difference was obtained for the thermal to gamma-ray scalar flux ratios as a function of core design.

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

4.18

ADVANCED NEUTRON SOURCE DESIGN: BURNOUT HEAT FLUX CORRELATION DEVELOPMENT

W. R. Gambill* T. Mochizuki†

[Abstract of *Trans. Am. Nucl. Soc.* 57, 298 (1988)]

In the Advanced Neutron Source (ANS) reactor fuel element region, heat fluxes will be elevated. Early designs corresponded to average and estimated hot spot fluxes of 11–22 and 21–22 MW/m². In either event, the development of a satisfactory burnout heat flux correlation is an important element among the many thermal hydraulic design issues, since the critical power ratio will depend in part on its validity. Relatively little work in the area of subcooled flow burnout has been published over the past 12 years.

We have compared seven burnout correlations and modifications thereof with several sets of experimental data. The best overall agreement between the correlations tested and these data is currently provided by a modification of Thorgenson's correlation.

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

*Chemical Technology Division.

†Kinki University, Osaka, Japan.

4.19

PRELIMINARY ANS REACTOR COLD SOURCE GAIN FACTOR CALCULATIONS FOR LIQUID DEUTERIUM AND LIQUID NITROGEN-15

D. L. Henderson

(Abstract of ORNL/TM-10824, November 1988)

Individual energy group gain factors are computed for liquid nitrogen-15 and liquid deuterium cold source moderators using simple one-dimensional slab and spherical geometry calculational models. The energy spectrum of the neutron source is assumed to be that of a thermalized Maxwellian flux at 20°C. The slab geometry calculations indicate that the optimum thickness for neutron transmission through a slab given an isotropic

incident flux is for wavelengths above .6 nm, approximately .20 m for liquid deuterium and between .28 and .32 m for liquid nitrogen-15. The gain factors at .8 nm corresponding to these thicknesses are 15.5 for liquid deuterium and 3.50 for liquid nitrogen-15. The spherical geometry analysis showed that the cold neutron current below 10 meV of 1.36 n/m²-s for the neutron component entering the cavity of a .16-m-thick liquid deuterium spherical shell exceeds the neutron leakage current of 1.08 n/cm²-s from a .38-m-diameter liquid deuterium solid sphere. However, the cold neutron factors for the neutron entering the void region are considerably lower than for the solid sphere case.

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

4.20

SOME PRELIMINARY DESIGN CONSIDERATIONS FOR THE ANS REACTOR COLD SOURCE

D. L. Henderson

[Abstract of *Trans. Am. Nucl. Soc.* 56, 561 (1988)]

The performance of a possible isotopic liquid nitrogen-15 (¹⁵N) (operating at 65 K) versus a liquid deuterium (operating at 20 K) cold neutron moderator has been investigated by computing the enhancement or gain in the cold neutron leakage fraction relative to the initial cold neutron source fraction for each moderator. One-dimensional slab and spherical geometry calculational models are used for the transport calculations to obtain the cold neutron group leakage fractions. An isotropic incoming boundary flux (left boundary for the slab) having a thermalized Maxwellian energy distribution at 20°C is used as the source condition. A 0.20-m-thick liquid ¹⁵N slab moderator and a 0.15-m-thick liquid deuterium slab moderator are considered. Liquid ¹⁵N and liquid deuterium spherical moderators with diameters of 0.34, 0.42, and 0.50 m are also investigated.

The transmitted gain factors at 0.8 nm for the liquid ¹⁵N and the liquid deuterium slab moderators are approximately 3.0 and 15.0. The reflected gain factor values at 0.8 nm are approximately 4.0 for liquid ¹⁵N and 21.0 for

liquid deuterium. Gain factor values for a 0.42-m-diameter sphere at 0.8 nm are approximately 6.0 for liquid ^{15}N and 32.0 for liquid deuterium. Though the liquid ^{15}N values are considerably below those computed for liquid deuterium, liquid ^{15}N represents a viable option should safety related issues prohibit the use of liquid deuterium as a moderating material.

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

4.21

PRELIMINARY ONE-DIMENSIONAL NEUTRONICS SCOPING STUDY FOR A CALIFORNIUM-252 COLD NEUTRON SOURCE MODERATING DEVICE

D. L. Henderson R. G. Alsmiller, Jr.

[Abstract of *Nucl. Instrum. Methods Phys. Res.* (in press)]

One-dimensional neutron transport calculations have been performed for a proposed Californium Cold Neutron Source experimental facility. The computations indicate that a peak cold neutron flux (flux below 10 meV) of 1.4×10^{13} neutrons/m²-s can be attained from a 500 mg Californium neutron source. The cold neutron exit (leakage) current from the spherical cryostat containing the liquid deuterium is 2.2×10^{12} neutrons/m²-s.

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

4.22

TIME-DEPENDENT SINGLE-COLLISION KERNELS FOR INTEGRAL TRANSPORT THEORY

D. L. Henderson C. W. Maynard*

[Abstract of *Nucl. Sci. Eng.* 102, 172 (1989)]

Time-dependent integral transport equation single-collision kernels for one-dimensional geometries corresponding to the steady state single-collision kernels found in the available literature have been calculated by making use of the Laplace transform technique, simple geometrical transformation

relationships and point kernel integrations. Using the convolution theorem, the time-dependent scalar flux is obtained by convoluting the single-collision kernel with the time-dependent source. Using the multiple collision formulation of the integral transport solution, isotropic sources that are delta distributions in time are considered in several examples. Analytical solutions for the uncollided and first collided scalar fluxes are obtained for a point source at the origin of an infinite medium and finite sphere of radius R and for a boundary source having an isotropic angular distribution directed into a semi-infinite medium and into a slab of thickness B. A closed form solution is obtained for the simple problem of uniformly distributed sources within an infinite medium.

Research sponsored by Sandia National Laboratories and Lawrence Livermore National Laboratory.

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4.23

GENERATION OF BROAD-GROUP NEUTRON/PHOTON CROSS- SECTION LIBRARIES FOR SHIELDING APPLICATIONS

D. T. Ingersoll R. W. Roussin
C. Y. Fu J. E. White

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 1, pp. 21:1-21:9 (1989)]

Two new multigroup cross-section libraries have been generated from ENDF/B-V data for two specific shielding applications. The first library was prepared for use in sodium-cooled reactor systems and is available in both broad-group (61-neutron, 23-photon) and few-group (22-neutron, 10-photon) energy structures. The second library was prepared for use in defense-related radiation shielding applications and is available in a broad-group (46-neutron, 23-photon) energy structure. The establishment of specifications for the libraries, especially the specific group structures and energy weighting functions, was an important part of the generation of both libraries.

Research sponsored by U.S. DOE Liquid Metal Converter Reactor Program and by Defense Nuclear Agency.

4.24

A USER'S GUIDE TO MICAP: A MONTE CARLO IONIZATION CHAMBER ANALYSIS PACKAGE

J. O. Johnson T. A. Gabriel

(Abstract of ORNL/TM-10340, January 1988)

A collection of computer codes entitled MICAP — A Monte Carlo Ionization Chamber Analysis Package has been developed to determine the response of a gas-filled cavity ionization chamber in a mixed neutron and photon radiation environment. In particular, MICAP determines the neutron, photon, and total response of the ionization chamber. The applicability of MICAP encompasses all aspects of mixed field dosimetry analysis including detector design, pre-experimental planning and post-experimental analysis.

The MICAP codes include: RDNDF for reading and processing ENDF/B-formatted cross-section files, MICRO for manipulating microscopic cross section data sets, MACRO for creating macroscopic cross-section data sets, NEUTRON for transporting neutrons, RECOMB for calculating correction data due to ionization chamber saturation effects, HEAVY for transporting recoil heavy ions and charged particles, PECSP for generating photon and electron cross section and material data sets, PHOTPREP for generating photon source input tapes, and PHOTON for transporting photons and electrons. The codes are generally tailored to provide numerous input options, but whenever possible, default values are supplied which yield adequate results. All of the MICAP codes function independently and are operational on the ORNL IBM 3033 computer system.

Research sponsored by Defense Nuclear Agency.

4.25

DESIGN CALCULATIONS FOR THE ANS COLD SOURCE

R. A. Lillie R. G. Alsmiller, Jr.

(Abstract of paper presented at the International Collaboration on Advanced Neutron Sources (ICANS-IX) Conference, Los Alamos, NM, October 3-7, 1988)

The calculational procedure, based on discrete ordinates transport methods, that is being used to carry out design calculations for the Advanced Neutron Source cold source is described. Calculated results on the gain in cold neutron flux produced by a liquid deuterium cold source are compared with experimental data and with calculated data previously obtained at the Institute Max von Laue-Paul Langevin in Grenoble, France. Calculated results are also presented that indicated how the flux of cold neutrons vary with cold source parameters.

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

4.26

CROSS-SECTION PROCESSING METHODOLOGY USED TO DESIGN THE ADVANCED NEUTRON SOURCE REACTOR

R. T. Primm, III

(Abstract of *Trans. Am. Nucl. Soc.* 57, 292 (1988))

Studies for the Advanced Neutron Source reactor have shown that the following conclusions regarding cross-section processing can be made. The use of a 27-group data library as a starting point appears to offer sufficient resolution in energy. The thermal flux depression in traversing from coolant to fuel is insignificant. If few-group diffusion calculations are to be performed with only one thermal group, then multiple, spatially dependent cross-section sets are needed for all principal nuclides. To account properly for thermalized neutrons that return to the core from the reflector, intracore plenum, or core central hole, one should use a fine-group, two-dimensional transport representation to collapse cross-section data.

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

4.27

GENERATION OF LUMPED FISSION PRODUCT CROSS SECTIONS FOR HIGH BURNUP, HIGHLY ENRICHED URANIUM FUEL

R. T. Primm, III N. M. Greene*

[Abstract of *Trans. Am. Nucl. Soc.* 56, 592 (1988)]

To estimate the Advanced Neutron Source reactor's performance as a function of time, it is necessary to model fuel depletion and the buildup of fission product poisons. An exact calculation of fission product buildup is not feasible, since there are several hundred fission product nuclides and concentrations that would have to be computed at a few hundred points in the reactor. Consequently, a simplified treatment in which a few fission products are represented explicitly and the remainder grouped into two lumped fission products is utilized. A methodology which accounts for the ANS reactor's short length, high-burnup, highly enriched U-235 fuel cycle was developed. Previous data were inadequate due to revised nuclear data, changes in the expected reactor fuel cycle, and the need for data in energy ranges previously not investigated.

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

*Computing and Telecommunications Division.

4.28

REACTOR PHYSICS STUDIES OF VARIOUS ADVANCED NEUTRON SOURCE REACTOR CORE CONFIGURATIONS

R. T. Primm, III

[Abstract of *Trans. Am. Nucl. Soc.* 59, 346 (1989)]

The VENTURE diffusion theory code was utilized to perform calculations with cross-section data from ENDF/B-V. The parameters varied in the study were total fueled core volume, number of elements in the core (number of vertical splits), and vertical distance between annuli (height of the split). The cores with higher fuel volume but smaller plenum thickness have greater reactivity. The more compact cores (both in terms of total fueled volume and plenum height) have higher efficiencies, i.e., for constant fission power among all

designs, the lower volumes would yield a higher peak thermal flux in the reflector. These calculations must be coupled with thermal-hydraulic analyses before selecting a specific geometry.

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

4.29

THE DORT TWO-DIMENSIONAL DISCRETE ORDINATES TRANSPORT CODE

W. A. Rhoades R. L. Childs*

[Abstract of *Nucl. Sci. Eng. (CCA)*, p. 88 (1988)]

DORT determines the flux or fluence of particles throughout one- and two-dimensional geometric systems due to sources generated as a result of particle interaction with the medium or incident upon the system from extraneous sources. The principal application is to the deep-penetration transport of neutrons and photons. Criticality (k-type and search) problems can be solved. Numerous printed edits of the results are available and results can be transferred to output files for subsequent analysis.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

4.30

3-D DISCRETE ORDINATES CALCULATIONS WITH PARALLEL-VECTOR PROCESSORS

W. A. Rhoades R. E. Flanery

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; *Proc. Vol. 2*, pp. 69:1-69:11 (1989)]

This study applies the concepts of parallel processing to a large three-dimensional discrete ordinates transport problem in a production Cray-CTSS environment. In noncurved geometry, the fluxes in various directions can be calculated in parallel, and the problem was restructured accordingly. In addition, natural parallelism in the acceleration of the fluxes was exploited. The degree of success hinged upon coping with delays encountered in attaching more than one processor to a single job.

Due to memory limitations on the system used, the largest contemporary production problems could not be run. However, when the corresponding amount of work was simulated, practical cost benefits of 24% were demonstrated on a 2-processor Cray X-MP. A modest benefit in real time was also noted, 13% under the most favorable conditions, although real time measurements are to be viewed with skepticism when obtained in the face of random competition from other users.

A test program was helpful in understanding the time-dependent and task-dependent opportunities for parallelism. It is shown that a good estimate of the cost benefits could have been obtained in advance from such information.

The parallel features had only a slight impact on the overall structure of the code, and the intention is to leave them in the production version under user control. It is likely that they can be adapted to future macrotasking systems without difficulty.

Research sponsored by Defense Nuclear Agency.

4.31

USER'S MANUAL FOR FERD-PC

B. D. Rodney

(Abstract of ORNL/TM-11028, April 1989)

FERD-PC is a modified version of the unfolding code FERD, rewritten in Microsoft FORTRAN and optimized for use on an IBM-PC or compatible computer. It can be used to correct observed pulse-height distributions for the nonideal response of a pulse-height spectrometer and has been successfully applied to the analysis of data from the Tower Shielding Facility at Oak Ridge National Laboratory (ORNL). Modifications to the original code have been incorporated to optimize program execution and run time, while still maintaining most input and output options supported by the original code. In addition, several changes have been made to include an interactive binning code, a flux integration code, and a plotting utility, which supports enhanced color graphics (EGA) and a HP 7475A or equivalent plotter. This manual describes these changes and enhancements, and covers essential information to set up and run FERD-PC. Sample problems are included to illustrate input and output procedures using various options of the code.

Research sponsored by U.S. DOE Energy Programs Division.

4.32

REACTOR PHYSICS METHODS FOR THE PRECONCEPTUAL CORE DESIGN OF THE ADVANCED NEUTRON SOURCE

J. M. Ryskamp* F. C. Difilippo
R. T. Primm, III

(Abstract of *Trans. Am. Nucl. Soc.* 57, 290 (1988))

Idaho National Engineering Laboratory (INEL) and Oak Ridge National Laboratory (ORNL) have been jointly working to develop and evaluate preconceptual reactor core configurations for the advanced neutron source. This paper reviews the reactor physics methods used to compute reactor parameters and demonstrates that the laboratories achieve good agreement on these parameters.

The single- and split-core reactor concepts examined are similar. Both have very small cores (≤ 35 l) inside a large tank of heavy water. These small, high-leakage, hard-spectrum cores are difficult to analyze, requiring advanced reactor physics methods. Reactor physics analyses were performed with ENDF/B-V cross-section data.

Four-group cross sections were calculated in different regions. In particular, the one thermal group ^{235}U cross sections have significant variation depending on the distance from the core periphery. Cross-section exposure dependence was also examined and included for some nuclides. Both laboratories primarily analyzed two-dimensional (r, z) core models with four-group diffusion theory (PDQ-7 for INEL and BOLD-VENTURE for ORNL). Excellent agreement was achieved on most parameters by INEL and ORNL for both core concepts. Difference in efficiencies between the single- and the split-core designs is largely related to the difference in core volumes.

In summary, the parameters computed by INEL and ORNL are close and accurate enough, however, for the two preconceptual reactor designs to be compared on a consistent basis.

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

*Idaho National Engineering Laboratory, Idaho Falls, ID.

4.33

DOS-HEATING6: A GENERAL CONDUCTION CODE WITH NUCLEAR HEAT GENERATION DERIVED FROM DOT-IV TRANSPORT CALCULATIONS

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(Abstract of ORNL/TM-10645, May 1988)

The HEATING6 heat conduction code is modified to (a) read the multigroup particle fluxes from a two-dimensional DOT-IV neutron-photon transport calculation, (b) interpolate the fluxes from the DOT-IV variable (optional) mesh to the HEATING6 control volume mesh, and (c) fold the interpolated fluxes with kerma factors to obtain a nuclear heating source for the heat conduction equation. The modified HEATING6 is placed as a module in the ORNL discrete ordinates system (DOS) and has been renamed DOS-HEATING6. DOS-HEATING6 provides the capability for determining temperature distributions due to nuclear heating in complex, multi-dimensional systems. All of the original capabilities of HEATING6 are retained for the nuclear heating calculation; e.g., generalized boundary conditions (convective, radiative, finned, fixed temperature or heat flux), temperature and space dependent thermal properties, steady-state or transient analysis, general geometry description, etc.

The numerical techniques used in the code are reviewed, and the user input instructions and JCL to perform DOS-HEATING6 calculations are presented. Finally a sample problem involving coupled DOT-IV and DOS-HEATING6 calculations of a complex space-reactor configuration is described, and the input and output of the calculations are listed.

Research sponsored by U.S. DOE Office of Nuclear Energy.

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4.34

IMPACT OF ^{235}U (MAT 9235) EVALUATION ON k_{eff} OF THERMAL SYSTEMS

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[Abstract of *Trans. Am. Nucl. Soc.* 59, 343 (1989)]

The impact on k_{eff} of thermal systems due to a proposed new evaluation of ^{235}U neutron cross sections for ENDF/B-VI (tentatively referred to as MAT 9235) was studied. There is considerable interest in the new evaluation because of the potential impact of the cross-section changes on k_{eff} of low- and high-enriched uranium systems. The cross-section changes proposed include the resolved and unresolved resonance regions, the thermal $\bar{\nu}$, the fission spectrum, and η . Of particular interest is the change in η below 1.86 eV. Several thermal benchmarks were calculated using ENDF/B-V and ENDF/B-VI evaluations of ^{235}U cross sections. The results showed that relative to the ENDF/B-V evaluation, the MAT 9235 (ENDF/B-VI) evaluation decreases $\Delta k/k$ by about 0.26% for the low-enriched benchmarks and about 0.35% for the high-enriched benchmarks. Values of the MAT 9235 η below 1.86 eV were found to differ from ENDF/B-V values by -1.1 to 3.5%. (Note that subsequent to the submission and acceptance of the paper, further revisions were made to the fission and capture cross sections. The revised calculations showed the change in $\Delta k/k$ was essentially 0% for the high-enriched benchmarks and about 0.1% for the low-enriched benchmarks. While there were some changes in η below 1.86 eV, the differences still lay within the range stated above.)

Research sponsored by U.S. DOE.

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HIGH ENERGY RADIATION AND PARTICLE TRANSPORT

4.35

INCLUSION OF CORRELATIONS IN THE EMPIRICAL SELECTION OF INTRANUCLEAR CASCADE NUCLEONS FROM HIGH-ENERGY HADRON-NUCLEUS COLLISIONS

F. S. Alsmiller R. G. Alsmiller, Jr.

[Abstract of ORNL/TM-11032, January 1989; also *Nucl. Instr. Methods Phys. Res. A278*, 713-721 (1989)]

The very high energy (5 GeV to 20 TeV) hadron-nucleus differential particle production model found in the Monte Carlo transport code FLUKA 87 has been adapted for inclusion in the transport code HETC88. The empirical selection of intranuclear cascade nucleons has been modified to provide simple correlations with the randomly selected number of hadron-nucleon collisions. A standard method of calculating the excitation energy of the compound nucleus preceding an added evaporation step by assuming the particles are produced in a one-dimensional nuclear well is applied. This method, coupled with the above correlations, leads to improved correlations of the excitation energy with the A and Z of the compound nucleus, and then to greatly improved distributions of the residual nuclei following evaporation. The frequency distributions of low energy ($\beta < 0.7$) charged particles show good agreement with experiment for 200 GeV protons incident on emulsions. Average multiplicities of shower and grey particles after evaporation for protons and pions incident on several elements are also compared with experiment.

Research sponsored by U.S. Department of Energy.

4.36

THE HIGH-ENERGY TRANSPORT CODE HETC88

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T. A. Gabriel O. W. Hermann*
J. M. Barnes*

(Abstract of paper presented at the Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989)

An upgraded version, HETC88, of the previously available High-Energy Transport Code

HETC is briefly described. In the upgraded code, the particle production model from hadron-nucleus nonelastic collisions at energies greater than 5 GeV has been revised. At nucleon and pion energies below 5 GeV, HETC88 is not different from the code previously available. In particular, provision is still made to allow neutrons with energies ≤ 20 MeV to be transported by one of the available codes designed for low-energy neutron transport.

Calculated results for the longitudinal distribution of the flux of neutrons with energy ≥ 40 KeV in the Tevatron tunnel when 900 GeV protons interact with N_2 in a warm section are presented and compared with experimental data. Some disagreements between the calculated and measured neutron flux are found. For 20 TeV protons incident on a large cylindrical iron target, calculated "star" density results from HETC88, FLUKA87, CASIM, and MARS10 are also compared.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

4.37

THE MODIFIED HIGH-ENERGY TRANSPORT CODE HETC AND DESIGN CALCULATIONS FOR THE SSC

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B. L. Bishop*

[Abstract of Trans. Am. Nucl. Soc. 56, 270 (1988)]

The proposed superconducting super collider (SSC) will have two circulating proton beams, each with an energy of 20 TeV. In order to perform detector and shield design calculations at these higher energies that are as accurate as possible, it is necessary to incorporate in the calculations the best available information on differential particle production from hadron-nucleus collisions. In this paper, the manner in which this has been done in the high-energy transport code (HETC) is described, and calculated results obtained with the modified code are compared with experimental data.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Computing and Telecommunications Division.

4.38

CALCULATED INCLUSIVE NEUTRON PRODUCTION FROM 400 GeV PROTON-NUCLEUS COLLISIONS

R. G. Alsmiller, Jr. F. S. Alsmiller
O. W. Hermann*

(Abstract of ORNL/TM-11257, August 1989)

Calculated inclusive neutron production from 400 GeV proton-nucleus collisions is presented and compared with experimental data. Target nuclei H, Be, Cu, and Pb are considered, and the comparisons cover the laboratory energy range of 20 to 400 GeV and angular range 0.7 to 10 mr. Moderately good agreement between the calculated and experimental data is found, but the agreement in the case of Be, Cu, and Pb is significantly better than in the case of H.

Research sponsored by U.S. DOE Office of High Energy Physics.

*Computing and Telecommunications Division.

4.39

THEORETICAL STUDIES OF HADRONIC CALORIMETRY FOR HIGH LUMINOSITY, HIGH ENERGY COLLIDERS

J. E. Brau* T. A. Gabriel

[Abstract of *Nucl. Instrum. Methods A* 279, 40 (1989); also ORNL/TM-10903, January 1989]

Experiments at the high luminosity, high energy colliders of the future will require optimization of the state of the art of calorimetry design and construction. During the past few years, the understanding of the basic phenomenology of hadron calorimeters has advanced through parallel theoretical and experimental investigations. The important underlying processes are reviewed to set the framework for the presentation of recent calculations of the expected performance of silicon detector based hadron calorimeters. Such devices employing uranium are expected to achieve the compensation condition (that is, $e/h \approx 1.0$) based on the understanding that has been derived from the uranium-liquid argon and uranium-plastic scintillator systems. In fact, even lead-

silicon calorimeters are found to achieve the attractive value for the e/h ratio of 1.16 at 10 GeV.

Research sponsored by U.S. DOE, Office of High Energy and Nuclear Physics.

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4.40

PROSPECTS FOR AND TESTS OF HADRON CALORIMETRY WITH SILICON

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(Abstract of ORNL/TM-10954, March 1989)

Hadron calorimetry with silicon may provide crucial capabilities in experiments at the high luminosity, high energy colliders of the future, particularly due to silicon's fast intrinsic speed and absolute calibration. The important underlying processes of our understanding of hadron calorimeters are reviewed to set the framework for the presentation of recent calculations of the expected performance of silicon detector based hadron calorimeters. Such devices employing uranium are expected to achieve the compensation condition (that is, the ratio of the most probable electron signal to hadron signal (e/h) is ≈ 1.0) based on the understanding that has been derived from the uranium-liquid argon and uranium-plastic scintillator systems. In fact, even lead-silicon calorimeters are found to achieve the attractive value for the e/h ratio of 1.16 at 10 GeV. An experimental test of these predictions is underway at CERN by the SICAPOL Collaboration.

Research sponsored by U.S. Department of Energy.

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4.41

THE CALCULATION OF COSMOGENIC NUCLIDE ABUNDANCE IN STONY METEORITES

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T. E. Ward*

(Abstract of oral presentation presented at a Symposium on the Cosmic Abundances of Matter, Minneapolis, MN, August 15-17, 1988)

In our calculations, use is made of Monte Carlo techniques for identifying nuclear collisions and specific nuclear reactions as well as establishing the transport of the incident nucleon and its generated nucleons. It is possible to use an integrated calculational approach in predicting the cosmogenic nuclide production rate and depth dependence. In particular, the High Energy Intranuclear and Internuclear Cascade Transport Code, HETC, is used to calculate directly the nuclide production rate due to spallation. When the neutron source results generated with HETC is linked to the low energy neutron transport code, MORSE, the neutron-induced cosmogenic nuclide, profiles can be calculated without resorting to extrapolations of excitation functions.

An incident cosmic ray spectrum to 200 GeV has been utilized in the calculation to predict the induced cosmogenic spectra. The neutron source spectra energy at the surface and at select depths in a 1-m diameter meteorite has been examined. In particular, one of the four compositional models has been utilized: L. Chondrite, H. Chondrite, Aubrite and C. Chondrite. Spallation and neutron-induced production similarly will be examined in detail for frequently measured radiogenic nuclides such as ^{22}Na , ^{36}Cl , ^{53}Mn , ^{59}Ni and ^{60}Co . It is seen that the spallation contribution dominates near the surface with neutron-induced contributions dominating deep within the meteorite. Since cosmogenic nuclide ratios are insensitive to incident flux normalization, select ratios are examined to give insight into inherent properties of the meteorite, such as preatmospheric size.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

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4.42

PRODUCTION RATES OF COSMOGENIC NUCLIDES IN STONY METEORITES

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O. Lazereth* M. S. Spergel†
T. E. Ward*

(Abstract of paper presented at the American Nuclear Society and National Bureau of Standards Conference on Fifty Years with Nuclear Fission, Gaithersburg, MD, April 26-28, 1989)

Monte Carlo calculations of Al^{26} and Mn^{53} production due to spallation induced by cosmogenic protons in model meteorite composition similar to L Chondrite has yielded predictions which are consistent with the observed decay rates in L Chondrite stony meteorites. The calculated Al^{26} production rate (54 dpm/kg) in a 1-m-diameter meteorite is within 1/2 S.D. of the mean (49 ± 11 dpm/kg) taken from 100 bulk determinations in L Chondrite samples compiled. Similarly calculated average value for Mn^{53} (223 dpm/kg) is consistent with one S.D. off the mean in the widely scattered Mn^{53} data (362 ± 113 dpm/kg) compiled.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

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4.43

DETERMINISTIC TRANSPORT CALCULATIONS OF DOSE PROFILES DUE TO PROTON BEAM IRRADIATION

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R. T. Santoro T. A. Gabriel
R. G. Alsmiller, Jr.

[Abstract of Trans. Am. Nucl. Soc. 56, 273 (1988)]

In this paper we present discrete ordinates solutions to the Spencer-Lewis equation for protons. In its present form, our code calculates the energy deposition profile and primary proton flux in x,y geometry due to proton beam irradiation. Proton energies up to 0.4 GeV are permissible.

Below this value, protons lose energy primarily through coulomb collisions with electrons. This is modeled using the continuous slowing down approximation (CSDA). The required stopping powers are obtained from the computer code SPAR, which has been included in the main program as a subroutine. Nuclear coulomb collisions are modeled using Rutherford scattering with the screening parameter given by Moliere. Due to the extreme anisotropy of proton coulomb scattering, the SMART scattering matrix technique has been applied. This method allows modeling of a large number of small angular deflections by relatively few large deflections. Currently, the code treats only primary protons. Cross sections for these reactions are obtained from the NCDATA code.

An analytic first collision source is used to model range straggling. Source particles with the same energy are given slightly different stopping powers to simulate straggling from energy loss fluctuations. These values are chosen such that the average stopping power and the percentage of range straggling are preserved.

Dose profiles have been calculated for several source and target geometries. The SN and Monte Carlo results are in excellent agreement, except near the peak. The discrepancy is probably due to diamond difference errors, differences in the treatment of range straggling, and considering HETC calculations do not include multiple nuclear scattering.

Research sponsored by U.S. Department of Defense; by Air Force Weapons Laboratory; and by the University of Arizona, Tucson, AZ.

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4.44

DETECTORS FOR THE SUPERCONDUCTING SUPER COLLIDER, DESIGN CONCEPTS, AND SIMULATION

T. A. Gabriel

(Abstract of ORNL/TM-11199, June 1989; also paper presented at the Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989)

The physics of compensation calorimetry is reviewed in the light of the needs of the Superconducting Super Collider (SSC) detectors. The

four major detector types: liquid argon, scintillator, room temperature liquids, and silicon are analyzed with respect to some of their strengths and weaknesses. Finally, general comments are presented which reflect the reliability of simulation code systems.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

4.45

CALOR89: THE CODE SYSTEM FOR CALORIMETER ANALYSIS AND DESIGN

T. A. Gabriel

(Abstract of paper presented at the Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989)

As part of a strong experimental high energy physics program, a substantial effort must be involved in calculational analysis of the detector system. This calculational capability must be fundamentally sound and based on previous interchange between theoretical calculations and experimental test programs. The CALOR89 system for analyzing calorimeters offers a solid approach for investigating all facets of detector systems and has been used in many calculational studies. CALOR89 is one of two major code systems recommended for analysis of SSC detector systems.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

4.46

CALORIMETER AND RELATED CALCULATIONS FOR THE SUPERCONDUCTING SUPER COLLIDER

T. A. Gabriel

(Abstract of ORNL/TM-10906, February 1989)

There are four topics to be covered in this paper. The first topic deals with the programs, the models, and the cross sections in the CALOR code package. Secondly, a discussion on compensating calorimetry as it applies to Fe/Si and U/Si calorimetry will be given. Thirdly, calculated results obtained on U/Si calorimeters using the CALOR system will be presented and discussed.

Finally, the calculations that the Oak Ridge National Laboratory are carrying out dealing with radiation damage at the proposed Superconducting Super Collider (SSC) are described.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

4.47

CALOR87: HETC87, MICAP, EGS4, AND SPECT, A CODE SYSTEM FOR ANALYZING DETECTORS FOR USE IN HIGH ENERGY PHYSICS EXPERIMENTS

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O. W. Hermann* J. O. Johnson

[Abstract of paper presented at the Workshop on Detector Simulation for the SSC, Argonne National Laboratory, August 24-28, 1987; Proc. pp. 50-60 (1988)]

A brief history of CALOR (HETC, EGS, MICAP, SPECT) is presented to indicate the evolution of this code system. Details concerning the current modifications and additions to the high-energy transport code, HETC, are also presented and new comparisons with experimental data are included to verify the new physics improvements.

Research sponsored by U.S. DOE Office of High Energy Physics and Nuclear Physics.

*Computing and Telecommunications Division.

4.48

THE PHYSICS OF COMPENSATING CALORIMETRY AND THE NEW CALOR89 CODE SYSTEM

T. A. Gabriel J. Brau*
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[Abstract of ORNL/TM-11060, March 1989; also paper presented at the IEEE 1988 Nuclear Science Symposium, Orlando, FL, November 9-11, 1988; Proc. IEEE Trans. on Nuclear Science 37(1), 14-17 (1989)]

Much of the understanding of the physics of calorimetry has come from the use of excellent radiation transport codes. A new understanding of compensating calorimetry was introduced four years ago following detailed studies with a new CALOR system. Now, the CALOR system has

again been revised to reflect a better comprehension of high energy nuclear collisions (HETC88) by incorporating a modified high energy fragmentation model from FLUKA87. This revision will allow for the accurate analysis of calorimeters at energies of 100's of GeV. Presented in this paper is a discussion of compensating calorimetry, the new CALOR system (CALOR89), the revisions to HETC, and recently generated calorimeter related data on modes of energy deposition and secondary neutron production ($E \leq 50$ MeV) in infinite iron and uranium blocks.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

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4.49

TRANSPORT CALCULATION OF COSMOGENIC NUCLIDE PRODUCTION IN STONY METEORITES

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O. Lazereth*

(Abstract of paper presented at the American Physical Society Meeting, Santa Fe, NM, October 12-15, 1988)

Cosmogenic nuclide production rate is calculated with the high energy nucleon and meson transport code HETC for spherical Chondrite Stony Meteorites of different sizes. The galactic proton flux (at solar flares) with proton energy ranging from 40 MeV to about 200 GeV is sampled via Monte Carlo technique for determining the incident proton energy and intensity on the meteorites. The cosmogenic nuclide production rate is calculated as a function of depth for different meteorite sizes. The estimation of the nuclide production due to low energy neutron transport is being undertaken with the help of transport code MORSE. The HETC predicted cosmogenic nuclide production rates will be presented.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

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4.50

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

**T. A. Gabriel J. O. Johnson
J. Brau***

[Abstract of paper presented at the Workshop on Detector Simulation for the SSC, Argonne National Laboratory, August 24-28, 1987; Proc. pp. 252-268 (1989)]

A new code system, MICAP, has been developed for the transport and production of low-energy (<20 MeV) neutrons, photons, and light and heavy ions. The results generated by this code system compare favorably with a wide variety of experimental data. Because of this success, MICAP can be used as a valuable tool in helping to analyze calorimeter systems. In particular, MICAP can be used as a valuable tool in helping to analyze calorimeter systems. In particular, MICAP is used in this paper to determine the practicality of hydrogen knock-in as a method of achieving compensation in a uranium/silicon calorimeter, i.e., $e/h=1$. The results indicate that compensation is probably possible but shower fluctuations may be increased.

Research sponsored by U.S. DOE Office of High Energy Physics and Nuclear Physics.

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4.51

SOURCES OF COMPENSATION IN HADRONIC CALORIMETERS

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[Abstract of ORNL/TM-10904, December 1988; also *Nucl. Instrum. Methods in Phys. Research A* 278, 441 (1989)]

Monte Carlo simulations are presented using the CALOR code system to study the design of a large hybrid hadron calorimeter system employing a warm liquid active medium (tetramethylsilane, $\text{Si}(\text{CH}_3)_4$) and uranium plates in addition to a

conventional Fe/plastic system. In the system described here, the uranium provides partial compensation by suppressing the electromagnetic cascade produced by incident electrons due to sampling inefficiencies. The results of the simulations also indicate that significant compensation is achieved (given small enough saturation) due to low energy recoil protons produced in collisions with low energy (1-20 MeV) cascade and fission neutrons in the active medium. Both compensation mechanisms are important to help balance the response of a calorimeter to incident electrons and hadrons, that is, to achieve a ratio of pulse heights ($e/h \approx 1$) which will lead to the best energy resolution.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

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4.52

ANALYSIS OF NEUTRONICS PARAMETERS MEASURED IN PHASE-II EXPERIMENTS OF THE JAERI/US COLLABORATIVE PROGRAM ON FUSION BLANKET NEUTRONICS. PART I: SOURCE CHARACTERISTICS AND REACTION RATE DISTRIBUTIONS

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T. A. Gabriel**

[Abstract of *Fusion Eng. Design* 9, 315 (1989)]

Fusion blanket neutronics parameters measured in the Phase II assembly have been analyzed at both JAERI and the US. Both parties have analyzed the experiments independently by using different nuclear data and calculational methods based on 3-D Monte Carlo and 2-D S_n codes. This part includes the results of the analysis on the source characteristics in the assembly and the reaction rate distributions in the

test zone consisting of Li_2O with and without a beryllium multiplier. The source characterization has been made by measuring the neutron spectrum and various reaction rates. These reactions include $^{58}\text{Ni}(n,2n)$, $^{58}\text{Ni}(n,p)$, $^{27}\text{Al}(n,\alpha)$, $^{93}\text{Nb}(n,2n)$, $^{197}\text{Au}(n,2n)$, and $^{197}\text{Au}(n,\gamma)$. The ratios of calculated to measured values are compared among both countries and the different nuclear data used. Considerable discrepancies have been observed for the $^{58}\text{Ni}(n,2n)$, $^{58}\text{Ni}(n,p)$, and $^{93}\text{Nb}(n,2n)$ reactions depending on which nuclear data was used, while good agreement is seen for the reactions $^{197}\text{Au}(n,2n)$ and $^{27}\text{Al}(n,\alpha)$. The distributions of these reaction rates in the test zone have also been analyzed to examine the prediction accuracy of neutronics parameters in a breeder zone. Using the recently measured cross sections at the FNS resulted in a significant reduction in the discrepancies for most reaction rates.

Research sponsored by U.S. Department of Energy.

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4.53

COMPARISON OF CALCULATED RESULTS WITH EXPERIMENTAL DATA FOR THE TRITIUM PRODUCTION RATES IN A Li_2O ASSEMBLY

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J. M. Barnes* T. A. Gabriel

[Abstract of *Nucl. Sci. Eng.* (in press); also ORNL/TM-11181, May 1989]

The Monte Carlo codes MORSE and MCNP have been used to calculate the tritium production from ≈ 14 MeV neutron reactions in a Li_2O assembly. Tritium production from neutron reactions with ^6Li and ^7Li nuclei were calculated

along the central axis of a 0.60-m diameter by 0.60-m-long assembly and four additional assemblies where sheets of stainless steel type 304 and polyethylene were placed in front of the Li_2O to simulate first wall and coolant materials. The calculated data are compared with measured data obtained at the Fusion Neutron Source at the Japan Atomic Energy Research Institute. The calculated data reproduce the measured data in shape, but differ from the measured data by 10–20% in the case of ^6Li and as much as 30% at some spatial locations for the ^7Li tritium production.

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

*Computing and Telecommunications Division.

4.54

ON-DIMENSIONAL S_N CALCULATIONS TO EVALUATE THE SHIELDING FOR AN ALPHA-PARTICLE CHARGE EXCHANGE NEUTRAL ANALYZER

R. T. Santoro W. K. Dagenhart*
J. M. Barnes†

(Abstract of ORNL/TM-10649, January 1988)

One-dimensional discrete ordinates calculations have been carried out to estimate the effectiveness of both concrete and stainless-steel plus borated water shadow shields in reducing the neutron and gamma-ray background levels at an alpha-particle charge exchange neutral analyzer. The system is proposed for studying the alpha particle and plasma characteristics of fusion machines with ignited plasmas such as the CIT. A stainless-steel-borated water shield was determined to be effective in reducing background counting rates.

Research sponsored by U.S. Department of Energy and U.S. Air Force Weapons Laboratory.

*Fusion Energy Division.

†Computing and Telecommunications Division.

SPACE DEFENSIVE SYSTEMS

4.55

SHIELD OPTIMIZATION PROGRAM, PART II: EFFECTS OF VAN ALLEN BELT RADIATION ON SDI WEAPON PLATFORMS

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J. O. Johnson J. D. Drischler
T. A. Gabriel M. S. Smith

(Abstract of ORNL/TM-10657, December 1988)

The effects of both natural and man-made Van Allen Belt (VAB) radiation at an altitude of 500 km are presented for various components of a prototypic space-based interceptor (SBI) weapon platform. The weapon platform is described in detail and represents the authors' concept of such a system. The calculated results show that the SBI platform will survive long term (10 years) exposure to natural VAB protons and electrons. However, when the electron belts are enhanced by the detonation of a nuclear weapon, high levels of radiation can be expected in components mounted on or near the surface of the spacecraft. These dose levels are sufficient enough to produce damage in the most sensitive components.

Research sponsored by Department of Defense and Air Force Weapons Laboratory.

*Computing and Telecommunications Division.

4.56

RECENT ORNL IMPROVEMENTS TO THE HULL HYDROCODE SYSTEM

T. J. Burns

(Abstract of ORNL/TM-10995, May 1989)

Modifications to the HULL hydrocode system are described. The modifications concern the problem generator of the system, KEEL. Revised algorithms for implementing combinatorial geometry, defining reference geometries, material "packaging," and restarting two- and three-dimensional calculations are described. The user input necessary to exercise the added/improved features is outlined and examples illustrating the revised capabilities are provided.

Research sponsored by Department of Defense and Air Force Weapons Laboratory.

4.57

THE OAK RIDGE NATIONAL LABORATORY STRATEGIC DEFENSE INITIATIVE SHIELD OPTIMIZATION PROGRAM

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B. L. Bishop* J. D. Drischler
J. O. Johnson R. A. Lillie
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[Abstract of ORNL/TM-10631, April 1988 and Executive Summary (ORNL/TM-10629, April 1988) by R. T. Santoro and T. A. Gabriel]

Scoping studies have been completed to estimate the radiation induced damage in silicon based electronic components carried on a satellite. The analyses were completed for natural (Van Allen belt protons and electrons, solar flares, and galactic cosmic rays) and man-made (nuclear and directed neutral particle beam weapons) radiation expected to be encountered by an SDI satellite or weapon platform. The Van Allen belt protons, depending on altitude and orbital inclination, were found to be the most stressing natural radiation threat. Nuclear weapon radiation, depending upon the weapon yield and distance of the detonation from the satellite, and neutral particle beam radiation were found to terminally destroy electronic components. Calculations were also made to estimate the amount of local shielding required to extend mission performance. These shields were optimized for minimum weight for specified damage thresholds. All of the calculations were carried out assuming the presence of a thin primary shield tailored specifically for survivability against an incident low mass kinetic energy weapon projectile and which affords minimal protection against energetic radiation.

Research sponsored by U.S. Department of Defense and Air Force Weapons Laboratory.

*Computing and Telecommunications Division.

4.58

SHIELD OPTIMIZATION PROGRAM, PART III: EFFECTS OF X-RAY RADIATION FROM NUCLEAR WEAPONS ON SDI WEAPON PLATFORMS

J. O. Johnson T. A. Gabriel
J. M. Barnes* J. D. Drischler
M. S. Smith R. T. Santoro

(Abstract of ORNL/TM-10985, March 1989)

Initial studies have been completed to estimate the radiation induced damage to the silicon based electronic components and other sensitive areas (fuel tanks) carried on a representative Space Based Interceptor (SBI) weapon platform. The SBI weapon platform model used in the studies represents the author's concept of such a system. The analysis was completed for the blackbody X-ray radiation environment emanating from a nuclear weapon detonation in space and considered blackbody temperatures in the range of 1 to 25 keV and exterior wall loadings in the range of 1 to 10 cal/cm².

The results indicate the dose to the sensitive components within the exterior hull of the platform was insufficient to cause any damage at a 1 to 3 cal/cm² exterior wall loading. At higher (5 to 10 cal/cm²) exterior wall loadings, some of the Kinetic Kill Vehicle (KKV) computers and sensors begin to receive doses sufficient enough to cause damage. The effects of shielding from within the platform architecture is seen by the different dose levels received in the KKV's and fuel tanks. Because of the low-dose levels to the components within the exterior hull of the platform, no additional shielding is required for these components and for low exterior wall loadings. However, sensors and electronic components on the surface or outside of the exterior hull will require some form of X-ray shielding to survive the effects of a nuclear weapon detonation yielding a wall loading of 1 cal/cm² or greater. All of the calculations were carried out for an unshielded SBI weapon platform to determine the radiation levels for which shielding must be designed to insure survivability of the electronic systems.

Research sponsored by Department of Defense and Air Force Weapons Laboratory.

* Computing and Telecommunications Division.

4.59

NUCLEAR WEAPON RADIATION EFFECTS ON A SPACE BASED INTERCEPTOR WEAPON PLATFORM

J. O. Johnson M. S. Smith
R. T. Santoro

(Abstract of paper to be presented at the 1990 HEART Conference, Naval Postgraduate School, Monterey, CA, February 12-16, 1990)

Initial studies have been completed to estimate the dose to the various electronic components and sensitive areas of an ORNL computer model of a representative Space Based Interceptor (SBI) weapon platform due to an exo-atmospheric nuclear weapon detonation. In particular, the damage resulting from incident neutrons, gamma-rays, and X-rays generated by the weapon detonation was assessed for the critical electronic components and for materials whose chemical/physical properties might degrade.

The neutron and gamma-ray source spectra employed in this study include a deuterium-tritium fusion reaction spectrum, a pure ²³⁵U fission spectrum and a prompt fission gamma-ray spectrum. Blackbody radiation spectra at temperatures (kT) of 2, 5, 10, and 20 keV were used with surface loadings in the range of 1-10 cal/cm² considered. An actual weapon spectrum may be constructed with a combination of the fusion and fission neutron and gamma-ray source spectra and the blackbody source spectra at various temperatures. Nuclear detonations directly above, directly in front, and at a 45 degree angle to the front and top faces of the weapon platform were considered to assess shielding effects inherent in the platform geometry. The nuclear weapon detonation was modeled such that the incident radiation spectra could be assumed monodirectional. The MORSE code was used to perform all neutron and gamma-ray calculations, and the EGS4 code was used to perform all X-ray calculations.

Initial results indicate neutron and gamma-ray dose and dose rate levels to the sensitive components within the SBI weapon platform may exceed design limits if the weapon is detonated within a critical radius. For example, the 1962 Starfish event had a yield of 1.4 MT, of which 1 MT was fission yield. At a distance of 91.4 km from the device, the X-ray surface loading is 1 cal/cm². Using this distance and yield, the total dose in the C³ bay critical box is 136 rads(Si) from

primary neutrons, primary gamma rays (prompt gamma rays), and secondary gamma rays. The dose rate assuming a 40 nanosecond pulse width, $\dot{\gamma}$, is 1.7×10^9 rads(Si)/sec. Consequently, the limiting factor with respect to damage is the dose rate.

The X-ray dose to the sensitive components within the exterior hull of the platform was not sufficient to cause any damage at a 1 cal/cm^2 exterior wall loading. However, if a 40 nanosecond pulse width is assumed, dose rates to the sensitive components in the range of 10^8 – 10^{12} rads/sec would occur and be large enough to cause damage. Consequently, the dose rate becomes the primary mode of failure even though the total dose is not large enough to cause any damage to the sensitive components. At higher wall loadings, some of the KKV computers and sensors begin to receive doses large enough to cause damage. Furthermore, the majority of the dose to the internal components of the SBI platform came from blackbody devices with temperatures greater than 10 keV. The low temperature devices will yield a higher flux of X-rays, but the incident energy will be insufficient to cause permanent damage to the internal electronic components.

Research sponsored by U.S. Air Force and U.S. DOE.

4.60

THE EFFECTS OF NATURAL AND ENHANCED VAN ALLEN BELT RADIATION ON A SPACE BASED WEAPON PLATFORM

R. T. Santoro J. M. Barnes*
J. O. Johnson

(Abstract of paper to be presented at the 1990 HEART Conference, Naval Postgraduate School, Monterey, CA, February 12–16, 1990)

Monte Carlo radiation transport calculations have been performed to estimate the effects of natural (protons and electrons) and weapon enhanced (electron) Van Allen Belt (VAB) radiation on a space deployed weapon platform. (The satellite configuration adopted for this study represents the authors' concept of such a system.) The purpose of this study was to evaluate the long term and transient effects of these radiation modes on the components of a satellite deployed in a circular

orbit at an altitude of 500 km and inclination angle of 0-deg. These kinds of satellites must survive long-term (up to 10 years) exposure to the natural radiation environment and the effects of enhanced radiation introduced when nuclear weapons are detonated in space.

This paper describes the platform/weapon system and its components, the Van Allen Belt spectra, the methods of calculation, and summarizes the radiation damage to platform components from VAB protons and electrons and enhanced electron belt radiation.

Research sponsored by U.S. Air Force.

*Computing and Telecommunications Division.

4.61

SHIELD OPTIMIZATION PROGRAM PART I: EXECUTIVE SUMMARY

R. T. Santoro T. A. Gabriel

(Abstract of ORNL/TM-11143, June 1989)

Detailed studies have been completed to estimate the radiation-induced damage in sensitive electronic components carried on a space-based interceptor weapons platform. The architecture of the interceptor was devised to be as realistic as possible. The analyses were completed for natural (Van Allen belt protons and electrons at an orbital altitude of 500 km) and man-made (nuclear weapons: neutrons, gamma-rays, X-rays, and pumped electron belts) radiation expected to be encountered by a SDI platform.

Studies have also been completed to determine the hydrodynamic responses of beryllium mirror surfaces to mono-energetic X-rays (1 and 2 keV). This work included the effects of impurities which are introduced into the surface during machining.

Finally, a comparison of the HULL and PUFF-TFT codes are presented which includes the thermo-mechanical response of an Al slab to 5 keV black body radiation.

Research sponsored by Department of Defense and Air Force Wright Aeronautical Laboratory.

4.62

MATERIAL RESPONSE TO INCIDENT X-RAYS

M. S. Smith

(Abstract of paper to be presented at the 1990 HEART Conference, Naval Postgraduate School, Monterey, CA, February 12-16, 1990)

This paper discusses results of hydrodynamic calculations to assess the thermo-mechanical response of various materials to energy loadings from incident X-rays. A beryllium mirror surface impurity study was performed to determine what effect surface impurities contribute to the material response. A second study, the LAMPSHADE survivability analysis, was conducted to ascertain whether the satellite debris shield would survive various X-ray energy loadings.

Research sponsored by Air Force Weapons Laboratory.

4.63

SHIELD OPTIMIZATION PROGRAM, PART IV: EFFECTS OF NEUTRON AND GAMMA-RAY RADIATIONS FROM NUCLEAR WEAPONS ON SDI WEAPON PLATFORMS

M. S. Smith J. O. Johnson
T. A. Gabriel J. M. Barnes*
J. D. Drischler R. T. Santoro

(Abstract of ORNL/TM-10975, March 1989)

Initial studies have been completed to estimate the radiation induced damage in silicon based electronic components onboard a representative Space Based Interceptor (SBI) weapon platform. The SBI weapon platform model used in the studies represents the author's concept of such a system. The analysis was completed for neutrons and gamma rays emanating from a nuclear weapon detonation in space.

Results indicate dose levels to the sensitive components within the SBI weapon platform may exceed design limits if the weapon is detonated within a critical radius. For example, a 1982 Starfish detonation at a distance of 91.4 km from the SBI weapon platform generates a total dose in the central instrument bay of 964 rads(Si). The dose rate, γ , assuming a 40 nsec deposition time, is 1×10^{10} rads(Si)/sec. All of the calculations were carried out for an unshielded SBI weapon platform

to determine the radiation levels for which shielding must be designed to ensure survivability of the electronic systems.

Research sponsored by U.S. Department of Defense and Air Force Weapons Laboratory.

* Computing and Telecommunications Division.

4.64

SHIELD OPTIMIZATION PROGRAM, PART V: A HYDRODYNAMIC COMPARISON USING HULL AND PUFF-TFT FOR A ONE-DIMENSIONAL ALUMINUM SLAB

M. S. Smith T. J. Burns
J. O. Johnson

(Abstract of ORNL/TM-11160, June 1989)

Results from the PUFF-TFT code were compared with those from HULL for a 1-dimensional aluminum slab subjected to X-rays from a 5-keV blackbody source. The source spectra was equivalent to a 1.5-Megaton thermonuclear device detonated at a distance of 10 km. Code predictions of density, internal energy, fracture locations, and axial stress were examined. With the exception of the magnitude of the axial stress, results from both codes were in agreement as to the characteristics of the material response.

Research sponsored by Department of Defense and Air Force Weapons Laboratory.

4.65

SHIELD OPTIMIZATION PROGRAM, PART VI: THE EFFECT OF IMPURITY LAYERS ON THE HYDRODYNAMIC RESPONSE OF A BERYLLIUM TARGET TO MONO-ENERGETIC X-RAYS USING THE PUFF-TFT CODE

M. S. Smith S. McNeany*
R. T. Santoro T. A. Gabriel

(Abstract of ORNL/TM-11038, March 1989)

Calculations were performed using the PUFF-TFT code to determine the thermo-mechanical response arising from incident mono-energetic X-rays on a beryllium substrate with a thin (300 Å) impurity layer. The impurities were introduced

into the material during typical fabrication processes. Responses were calculated for 5 nanosecond square wave pulses of monoenergetic X-rays (1 and 2 keV) with fluence levels corresponding to surface loadings of 1 and 5 cal/cm². The presence of these surface impurities was found to significantly alter the thermal response of the medium. As the concentration of surface impurities increased, the energy deposition increased and the temperature gradient increased. In some cases, additional impurities resulted in a phase change in the medium. For the most part, the mechanical response was unaffected by the surface impurity concentration.

Research sponsored by U.S. DOE Office of High Energy and Nuclear Physics.

*Engineering Technology Division.

4.66

INITIAL EFFECTS OF NUCLEAR WEAPON X-RADIATION ON THE LAMPSHADE ORBITAL DEBRIS SATELLITE SHIELD

M. S. Smith R. T. Santoro

(Abstract of ORNL/TM-11321, September 1989)

One-dimensional thermal-hydrodynamic calculations have been carried out to estimate the response of the lead bumper plate and tantalum liquidation screen of the LAMPSHADE orbital debris satellite shield. The mass loss fraction in the solid, liquid, and vapor phases as a function of time after irradiation for several typical incident x-ray spectra and fluences were calculated using the PUFF-TFT code. The material losses did not exceed 2% and fracture and spallation were confined to the surface region with no apparent reduction in the performance of these components against incident debris.

Research sponsored by U.S. DOE and Air Force Weapons Laboratory.

MATHEMATICAL MODELLING OF NON-LINEAR SYSTEMS INCLUDING COMBAT

4.67

A COMPARISON BETWEEN THE PROPAGATORS METHOD AND THE DECOMPOSITION METHOD FOR NONLINEAR EQUATIONS

Y. Y. Azmy D. G. Cacuci*
V. Protopopescu

(Abstract of ORNL/TM-11316 (in press))

Recently, a new formalism for solving nonlinear problems has been formulated. The formalism is based on the construction of advanced and retarded propagators that generalize the customary Green's functions in linear theory. One of the main advantages of this formalism is the possibility of

transforming nonlinear differential equations into nonlinear integral equations that are usually easier to handle theoretically and computationally. The aim of this paper is to compare, on an example, the performances of the propagator method with other methods used for nonlinear equations, in particular, the decomposition method. The propagator method is stable, accurate, and efficient for all initial values and time intervals considered, while the decomposition method is unstable at large time intervals, even for very conveniently chosen initial conditions.

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

*University of California at Santa Barbara, Santa Barbara, CA.

4.68

TWO-DIMENSIONAL MAPS GENERATED BY COMPETITIVE SYSTEMS

Y. Y. Azmy V. Protopopescu

(Abstract of ORNL/TM-11026, February 1989)

By discretizing time and space in a PDE model for competitive systems, we derive the corresponding discrete maps. We analyze these maps from an analytical and numerical viewpoint with emphasis on the military interpretation of the system. For the one-species map we study the effect of convection on the bifurcation behavior and we find periodic solutions. For the two-species map, we limit our analysis to an illustrative example, but we indicate the general procedure.

Research sponsored by Defense Advanced Research Projects Agency, Application and Computation.

4.69

STATIONARY FLOWS FROM A MODEL BOLTZMANN EQUATION

Y. Y. Azmy V. Protopopescu

[Abstract of paper presented at the 16th International Symposium on Rarefied Gas Dynamics, Pasadena, CA, July 10-16, 1988; Proc. *Progress in Astronautics and Aeronautics*, Vol. 118, pp. 15-28 (1989)]

The one-dimensional Boltzmann equation model of Ianiro and Lebowitz is generalized by allowing the collision frequency to be an arbitrary positive function of position and by including more general boundary conditions. Conservation laws and explicit solutions are derived, and macroscopic quantities obtained from the stationary Bhatnagar-Gross-Krook (BGK) variant of the model are compared with available experimental data.

Research sponsored by U.S. Department of Energy.

4.70

EXACT SOLUTIONS FOR A SEMILINEAR HYPERBOLIC SYSTEM WITH GENERAL QUADRATIC INTERACTIONS

V. C. Boffi* V. Protopopescu
Y. Y. Azmy(Abstract of *Nuovo Cimento D* (in press))

The approximate conservation laws for a binary gas mixture with quadratic interactions can

be written as a system of two semilinear hyperbolic equations. By using the method of characteristics the study of this system is reduced to the study of a system of nonlinear ordinary differential equations, for which we find several classes of exact solutions. Exact integrability conditions are found for ODE systems of generalized Lotka-Volterra type. Some situations are also considered, in which the characteristic method cannot be applied and exact solutions are obtained via an operator method.

Research sponsored by Defense Advanced Research Projects Agency Application and Computation and U.S. Department of Energy.

*Bologna, Italy.

4.71

CANONICAL PROPAGATORS FOR NONLINEAR SYSTEMS: THEORY AND SAMPLE APPLICATIONS

D. G. Cacuci* V. Protopopescu

(Abstract of paper presented at the Third International Workshop on Mathematical Aspects of Fluid and Plasma Dynamics, Salice Terme, Italy, September 26-30, 1988)

A new canonical formalism for solving general nonlinear systems is presented. Fundamental to this formalism is the construction of forward (advanced) and backward (retarded) propagators that yield the problem's solution *exactly*, by propagating volume, surface, and initial sources. These propagators also satisfy reciprocity and semi-group properties. Therefore, they represent a generalization to nonlinear systems of the Green's functions from linear theory. Several examples are presented to illustrate the application of the algorithm as well as its numerical advantages over alternative methods.

Research sponsored by Department of Defense Joint Chiefs of Staff and U.S. Department of Energy.

*University of California, Santa Barbara, CA.

4.72

PROPAGATORS FOR NONLINEAR SYSTEMS

D. G. Cacuci* V. Protopopescu

(Abstract of *J. Physics A* 22, 2399 (1989))

A canonical formalism based on forward and backward propagators is developed for problems described by systems of general nonlinear equations. These propagators are shown to yield the

problem's solution by propagating exactly the bulk/surface/initial sources. They naturally generalize to nonlinear problems the Green's functions of linear theory. Unlike the customary Green's functions, though, the forward and backward propagators depend parameterically and nonlinearly on the problem's solution; however, the propagators themselves satisfy linear equations that can, in principle, be solved by methods of linear theory. Three examples, comprising both scalar and vector problems, are presented to highlight the main points underlying the application of this formalism.

Research sponsored by U.S. Department of Energy.

*University of California, Santa Barbara, CA.

4.73

PARABOLIC SYSTEMS WITH NONLINEAR COMPETITIVE INTERACTIONS

C. Cosner* S. Lenhart
V. Protopopescu

[Abstract of ORNL/TM-11071, January 1989; also *IMA J. of Applied Math.* (in press)]

A parabolic system with nonlinear local or nonlocal interactions is considered, with specific applications to the description of competition/combustion situations. Global existence and comparison results are proven under suitable assumptions on the interaction terms. Comparisons with solutions of the "equivalent" ordinary differential (space independent) model, that has been previously used in modelling combat, are of special interest. The stationary state of such a system - corresponding to a stalemate - is also considered. Under certain conditions on the interaction, domain size and boundary conditions, a uniqueness result is obtained for the stationary state. A simple example shows that these conditions are sharp and uniqueness may be lost when they are not fulfilled.

Research sponsored by U.S. DOE and Defense Advanced Research Projects Agency.

*University of Miami, Miami, FL.

4.74

OPTIMAL CONTROL THEORY OF LOAD-FOLLOWING AND PARAMETER- TRACKING OF NONLINEAR SYSTEMS: AN APPLICATION OF PONTRYAGIN MAXIMUM PRINCIPLE TO REACTOR DYNAMICS

C. March-Leuba* R. B. Perez

(Abstract of ORNL/TM-10662, December 1987)

A demand-following and parameter-tracking algorithm has been developed which utilizes the Pontryagin Maximum Principle (PMP). Starting from a variational principle, we have derived the methodology for the construction of a Hamiltonian function, with the analytical properties required by the application of the Pontryagin Maximum Principle method to Free Terminal Time optimization problems. A crucial result has been the conversion of the two point boundary value problem, typical of the Pontryagin Maximum Principle method for nonlinear systems, into a noniterative initial value problem. The introduction of sensor signals information, as a set of differential equations complementing the model's equation, allows the reformulation of parameter tracking algorithms as control optimization problems, where the demands are the plant signals, and the controls are the time-varying plant parameters. The present algorithm allows correction for the time delays which affect the information flowing from the plant. The control algorithm presented in this paper has been validated against a nonlinear model of a nuclear power plant with time-varying parameters.

Research sponsored by U.S. DOE Office of Reactor Physics and Shielding.

*University of Tennessee, Knoxville, TN.

4.75

NOISE AND NONLINEAR PHENOMENA IN NUCLEAR SYSTEMS

Editors:

J. L. Munoz-Cobo* F. C. Difilippo

[Abstract of book, Series B: Physics Vol. 192, Plenum Press, New York (1989)]

The main goal of the workshop was to facilitate and encourage the application of recent developments in the physical and mathematical sciences to the analysis of deterministic and stochastic processes in nuclear engineering. In contrast with the rapid growth (triggered by computer developments) of nonlinear analysis in other branches of the physical sciences, the theoretical analysis of nuclear reactors is still based on linearized models of the neutronics and thermal-hydraulic feedback loop, an approach that ignores some intrinsic nonlinearities of the real system. The subject of noise was added because of the importance of the noise technique in detecting abnormalities associated with perturbations of sufficient amplitude to generate nonlinear processes.

Thirty-five presentations were discussed by participants from fourteen countries and international organizations at the Polytechnical University of Valencia (Spain). A cross-fertilization of ideas was observed; for example, new stochastic tools to detect nonlinear processes in nuclear power plants are being developed, whereas the paradigm of noise perturbations in a distorted potential well is being applied to analyze jumping processes in the internal vibrations of nuclear reactors. The papers presented at the meeting fall into some of the following categories:

- Basic methodology to analyze nonlinear deterministic and stochastic processes.
- Deterministic analysis of nuclear dynamics, transition to chaos.
- Noise theory and its application to the surveillance and diagnosis of nuclear systems.

The Organizing Committee gratefully acknowledges the financial support of the following institutions: Scientific Affairs Division of NATO, Dirección General de Investigación Científica y Técnica of Spain, and the Polytechnical University of Valencia. Their contributions made the workshop possible.

Research sponsored by NATO Office of Scientific Affairs.

*Polytechnical University of Valencia, Valencia, Spain.

4.76

GLOBAL EXISTENCE FOR SYMMETRIC DISCRETE VELOCITY MODELS

V. Protopopescu

[Abstract of paper in the Proceedings of the Workshop on Discrete Models Lattice Gas Dynamics and Foundations of Hydrodynamics, Torino, Italy, September 19–24, 1988, p. 258, World Scientific, Singapore (1989)]

For symmetric discrete velocity models, some generalizations of previous global existence proofs are given to include bounded geometries, continuous models, and stationary states with no momentum conservation. Additional results and simpler proofs are obtained for completely symmetric models.

Research sponsored by Organization of the Joint Chiefs of Staff, Department of Defense.

4.77

AN EXAMPLE OF A REACTION-DIFFUSION SYSTEM WITH NONLINEAR COMPETITIVE INTERACTIONS

V. Protopopescu

(Abstract of paper presented at the 11th International Conference on Transport Theory, Blacksburg, VA, May 22–26, 1989)

An example of a parabolic system with nonlinear local or nonlocal interactions is considered, with specific applications to the description of competition situations. Under suitable assumptions on the interaction terms, one can derive global existence as well as a comparison result between the PDE solutions and the "lumped" (space-integrated) ODE solutions. The uniqueness issue for the stationary state of the system – corresponding to a stalemate – is also considered. The discrete version of the system is then constructed and some preliminary results for the two-species one-index map and for the one-species two-index map are discussed.

Research sponsored by Defense Advanced Research Projects Agency Applications and Computation and U.S. Department of Energy.

4.78

COMBAT MODELING WITH PARTIAL DIFFERENTIAL EQUATIONS

V. Protopopescu R. T. Santoro
J. Dockery* R. L. Cox†
J. M. Barnes†

(Abstract of ORNL/TM-10636, November 1987)

A new analytic model based on coupled nonlinear partial differential equations is proposed to describe the temporal and spatial evolution of opposing forces in combat. Analytic descriptions of combat have been developed previously using relatively simpler models based on ordinary differential equations (e.g., Lanchester's equations of combat) that capture only the global temporal variation of the forces, but not their spatial movement (advance, retreat, flanking maneuver, etc.). The rationale for analytic models and, particularly, the motivation for the present model are reviewed. A detailed description of this model in terms of the mathematical equations together with the possible and plausible military interpretation are presented. Numerical solutions of the nonlinear differential equation model for a large variety of parameters (battlefield length, initial force ratios, initial spatial distribution of forces, boundary conditions, type of interaction, etc.) are implemented. The computational methods and computer programs are described and the results are given in tabular and graphic form. Where possible, the results are compared with the predictions given by the traditional Lanchester equations. Finally, a PC program is described that uses data downloaded from the mainframe computer for rapid analysis of the various combat scenarios.

Research sponsored by U.S. DOD Organization of the Joint Chiefs of Staff, Command, Control, and Communications.

*Organization of the Joint Chiefs of Staff, Command, Control, and Communications, The Pentagon, Washington, DC.

†Computing and Telecommunications Division.

4.79

TWO-DIMENSIONAL COMBAT MODELING WITH PARTIAL DIFFERENTIAL EQUATIONS

P. Rusu*

(Abstract of ORNL/TM-10973, December 1988)

The system of partial differential equations introduced to model combat in one spatial dimension has been extended to include two spatial dimensions and has been numerically integrated to demonstrate its capability to describe maneuver. The analysis of a turning maneuver is demonstrated.

Research sponsored by Defense Advanced Research Projects Agency Applications and Computation.

*University of Colorado, Boulder, CO.

4.80

MATHEMATICAL DESCRIPTIONS OF OFFENSIVE COMBAT MANEUVERS

R. T. Santoro P. Rusu*
J. M. Barnes†

(Abstract of ORNL/TM-11000, January 1989)

Mathematical descriptions of several forms of offensive maneuvers have been calculated using a recently developed two-dimensional nonlinear partial differential equation (PDE) model for describing conflict between opposing forces. Engagement scenarios wherein the attacking force(s) employs the frontal attack, turning movement, envelopment, or infiltration against a fixed defensive force are presented for various combinations of troop and firepower ratios. The time and spatial distributions of the forces are displayed in graphical form along with approximate attrition rates as a function of battle duration. The results establish that the PDE formalism replicates these maneuver forms within the constraints and present development of the model.

Research sponsored by Defense Advanced Research Projects Agency Applications and Computation.

*University of Colorado, Boulder, CO.

†Computing and Telecommunications Division.

4.81

NONLINEAR MAPS WITH COMPETITIVE INTERACTIONS: FIXED-POINTS, BIFURCATIONS, AND CHAOTIC ATTRACTORS

**D. F. Scollan* Y. Y. Asmy
V. Protopopescu**

(Abstract of ORNL/TM-11315, September 1989)

We examine several aspects of the dynamical behavior of competitive systems modeled by nonlinear maps. In the second chapter of this report, we analytically investigate some features of special cases of such maps, and we use the symbolic manipulator MACSYMA to derive expressions for the linearized systems' eigenvalues. These enable us to determine the linear stability of some of the fixed and periodic points of these maps, and in some cases, yield the regions of attraction in phase space.

In Chapters 3-5 we extend the analysis to a more general form of competitive systems. The

two-species one-index system and the one-species two-index map are numerically explored in search for interesting bifurcation and/or chaotic regimes over a large range of parameters. We will show that the system (1-1-4) with linear attrition displays stable, interesting behavior for a large region of parameter space even if the quadratic self-repression is taken very small. We will also show that small quadratic self-repression combined with bilinear attrition generally results in steady-state solutions with one species zero or in unbounded iterates.

In Chapter 6, we describe the method used to obtain an approximate estimate of the correlation dimensions of the chaotic attractor presented in Chapter 3. We also propose a new method to evaluate the correlation dimension of a chaotic attractor using statistical analysis methods.

Research sponsored by Defense Advanced Research Projects Agency Application and Computation and U.S. DOE.

*Penn State University, University Park, PA.

NUCLEAR WEAPON EFFECTS

4.82

MASH, THE MONTE CARLO ADJOINT SHIELDING CODE

**M. B. Emmett* W. A. Rhoades
J. O. Johnson**

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 1, pp. 42:1-42:10 (1989)]

The Monte Carlo Adjoint Shielding (MASH) code calculates protection factors for armored military vehicles by coupling a forward discrete ordinates calculation with an adjoint Monte Carlo calculation. The discrete ordinates calculation determines the fluence on a coupling surface surrounding the vehicle due to an external neutron/photon source. The Monte Carlo calculation determines the effectiveness of the fluence at that surface in causing a response in a detector within the vehicle, i.e., the "dose importance" of the surface fluence. A coupling code folds the fluence together with the dose importance, giving the desired dose response. This coupling code can also rotate the

vehicle, move it to different distances from the source, and perturb the energy response of the detector.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

4.83

A RE-EVALUATION OF ³²S(n,p) CROSS SECTIONS FROM THRESHOLD TO 5 MeV

C. Y. Fu

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 1, pp. 17:1-17:11 (1989)]

Two evaluations of the ³²S(n,p) reaction cross sections, presently being used for the Nagasaki and Hiroshima dosimetry studies, are of low quality and are in serious disagreement. The present re-evaluation of these cross sections was intended to be the most advanced possible and was based on

an exhaustive data search that uncovered an additional data set, a Bayes-theorem code for combining experimental data with uncertainties, a special procedure for including the effects of energy resolutions in data averaging, and the application of the much-improved ENDF/B-VI standards. Correlations in the experimental data were evaluated and tested for their effects but were not used for the final results because such correlations caused errors in the presence of resonances. The new results below 5 MeV (the upper limit of the present need) were combined with the ENDF/B-V dosimetry data above 5 MeV to generate a complete file, including covariances from threshold to 20 MeV. These point data were processed into two Vitamin-E 174-group sets, one with a constant energy weighting and the other with a Maxwell-1/E-fission weighting.

Research sponsored by Defense Nuclear Agency.

4.84

FALLOUT FACTS FOR NUCLEAR-BATTLEFIELD COMMANDERS

C. M. Haaland

[Abstract of ORNL/TM-11193 (in press)]

The basic phenomenology of radioactive fallout from nuclear detonations is described non-mathematically for military commanders who may become engaged in nuclear battle. Subjects include a description of fallout debris, the process of formation and deposition, and hazards to personnel. Comparisons are made between initial nuclear radiation and radiation from fallout. A radiation rate and exposure forecasting method is presented for situations where the source of fallout and rate of decay are unknown. Additional research is recommended for (1) development of improved methods for estimating casualties resulting from combined exposure to initial nuclear radiation and fallout radiation; and (2) improving the estimate of the K-factor (how much of the radioactive material comes to the ground as early fallout).

Research sponsored by U.S. Department of Energy.

4.85

AN APPROXIMATION FOR BLACK-BODY X-RAY TRANSPORT IN AIR

C. M. Haaland R. T. Santoro
J. M. Barnes*

[Abstract of *Applied Radiation and Isotopes* (in press)]

This paper describes a simplified method for approximating the air-transported x-ray spectrum from nuclear detonations in the atmosphere. The early fireball of a nuclear detonation emits intense x-ray radiation that can be approximated by the spectrum from a black-body at a temperature of around 10^{-7} – 10^{-8} K. A number of procedures have been devised for calculating the transport of photons and neutrons in various media. Tables have been prepared that provide the x-ray flux at a distance R from a nuclear detonation in the atmosphere for a limited set of parameters. The method described here reduces computational time such that a desk-top computer can provide results that match detailed Monte Carlo calculations within $\pm 10\%$ for a wide range of conditions. The approximation requires a computation time of 1–2 seconds on a desk-top computer with numerical coprocessor, whereas the comparable calculation using the Monte Carlo code typically requires 10–15 seconds on a Cray computer.

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

*Computing and Telecommunications Division.

4.86

AN APPROXIMATION FOR BLACK-BODY X-RAY TRANSPORT IN AIR

C. M. Haaland R. T. Santoro
J. M. Barnes*

(Abstract of ORNL/TM-10610, August 1988)

A simplified method is presented for approximating the air-transported x-ray spectrum from nuclear detonations in the atmosphere. Computational time is reduced such that a desk-top computer can provide results that match, within $\pm 10\%$ for a wide range of conditions, Monte Carlo

results which require about the same computation time on a Cray. The method consists of (1) representing the black-body continuous spectrum by discrete emission windows, (2) consulting tables of photon buildup factors for the discrete emission energies, (3) unfolding the buildup photons by using air kerma response functions and an assumption for redistributing these photons to windows of lower energy, and (4) applying cutoff and weighting factors to improve the correlation with the Monte Carlo benchmark calculations.

Research sponsored by U.S. Department of Energy and U.S. Air Force.

*Computing and Telecommunications Division.

4.87

DABL69: A BROAD-GROUP NEUTRON/ PHOTON CROSS-SECTION LIBRARY FOR DEFENSE NUCLEAR APPLICATIONS

D. T. Ingersoll R. W. Roussin
C. Y. Fu J. E. White

(Abstract of ORNL/TM-10568, June 1989)

A new multigroup cross-section library has been generated from ENDF/B-V data for use in defense-related radiation shielding applications. The library is available in a broad-group (46-neutron, 23-photon) energy structure and is designated DABL69. The establishment of specifications for the library, especially the specific group structure and energy weighting functions, was an important part of the generation of the library. The energy group structure contains some special tailoring to the oxygen and nitrogen cross sections and improved energy resolution in the range of 100-1000 keV where the iron cross section is highly structured. The library contains most materials of importance in defense-related shielding problems and includes several reference source spectra and response functions. The library is available in two formats including the commonly used ANISN format and the more versatile AMPX master format.

Research sponsored by Defense Nuclear Agency.

4.88

SENSITIVITY/UNCERTAINTY ANALYSIS FOR FREE-IN-AIR TISSUE KERMA DUE TO INITIAL RADIATION AT HIROSHIMA AND NAGASAKI

R. A. Lillie B. L. Broadhead*
J. V. Pace, III* D. G. Cacuci†

[Abstract of *Nucl. Sci. Eng.* 100, 105 (1988)]

Uncertainty estimates and cross correlations by range/survivor have been calculated for the Hiroshima and Nagasaki free-in-air (FIA) tissue kerma obtained from two-dimensional air/ground transport calculations. The uncertainties due to modeling parameter and basic nuclear transport data uncertainties were calculated for 700-, 1000-, and 1500-m ground ranges. Only the FIA tissue kerma due to initial radiation was treated in the analysis; the uncertainties associated with terrain and building shielding and phantom attenuation were not considered in this study. Uncertainties of ~20% were obtained for the prompt neutron and secondary gamma kerma and 30% for the prompt gamma kerma at both cities. The uncertainties on the total prompt kerma at Hiroshima and Nagasaki are ~18% and 15%, respectively. The estimated uncertainties vary only slightly by ground range and are fairly high correlated. The total prompt kerma uncertainties are dominated by the secondary gamma uncertainties, which in turn 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.

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4.89

RADIATION EXPOSURE INSIDE REINFORCED CONCRETE BUILDINGS AT NAGASAKI

**W. A. Rhoades R. L. Childs*
D. T. Ingersoll**

(Abstract of ORNL/TM-10500, May 1980)

The biological effects on the residents of Hiroshima and Nagasaki due to initial irradiation exposure during the nuclear attacks of World War II were recognized immediately as an important source of information. After the war, an extensive effort gathered data concerning the locations of individuals at the time of the attack and their subsequent medical histories. The data from personnel located in reinforced concrete buildings are particularly significant, since large groups of occupants received radiation injury without complications due to blast and thermal effects.

In order to correlate the radiation dose with physiological effects, the dose to each individual must be calculated. Enough information about the construction of the buildings was available after the war to allow a radiation transport model to be constructed, but the accurate calculation of penetration into such large, thick-walled three-dimensional structures was beyond the scope of computing technology until recently. Now, the availability of Cray vector computers and the development of a specially-constructed discrete ordinates transport code, TORT, have combined to allow the successful completion of such a study.

This document describes the radiation transport calculations and tabulates the resulting dose by source component and individual case location.

An extensive uncertainty analysis is also included. These data are to be used in another study as input to a formal statistical analysis, resulting in a new value for the LD50 dose, i.e., the dose at which the mortality risk is 50%.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

4.90

NEW DOSE MORTALITY DATA BASED ON 3-D RADIATION SHIELDING CALCULATION FOR CONCRETE BUILDINGS AT NAGASAKI

**W. A. Rhoades R. L. Childs*
D. T. Ingersoll**

(Abstract of paper presented at the 7th International Conference on Radiation Shielding, Bournemouth, UK, September 12-16, 1982; Proc. Vol. III, pp. 1145-1154 (1980))

The analysis of radiation doses received during the World War II attack on Nagasaki provides an important source of biomedical information. More than 40 years after the war, it has been possible to make a satisfactory calculation of the doses to personnel inside reinforced concrete buildings by use of a 3-dimensional discrete ordinates code, TORT. The results were used to deduce a new value of the LD50 parameter that is in good agreement with traditional values. The new discrete ordinates software appears to have potential application to conventional radiation transport calculations as well.

Research sponsored by Defense Nuclear Agency.

*Computing and Telecommunications Division.

RISK ASSESSMENT AND REACTOR SAFETY

4.91

USER'S GUIDE FOR PRISIM ARKANSAS NUCLEAR ONE—UNIT 1: VOL. 1—PROGRAM FOR INSPECTORS VOL. 2—PROGRAM FOR REGULATORS

D. J. Campbell* V. H. Guthrie*
J. R. Kirchner* J. Q. Kirkman*
H. M. Paula* B. C. Ellison*
F. M. Dycus* J. A. Farquharson*
G. F. Flanagan

[Abstract of ORNL/TM-10804/V1&2 (NUREG/CR-5021, Vols. 1 & 2), March 1988]

These user's guides are designed to teach NRC inspectors and NRC regulators how to access probabilistic risk assessment information from the two Plant Risk Status Information Management System (PRISIM) programs developed for Arkansas Nuclear One — Unit One (ANO-1). Volume 1 describes how the PRA information available in Version 1.0 of PRISIM is useful for planning inspections. Using PRISIM, inspectors can quickly access PRA information and use that information to update risk analysis results, reflecting a plant's status at any particular time. Volume 2 describes how the PRA information available in Version 2.0 of PRISIM is useful as an evaluation tool for regulatory activities. Using PRISIM, regulators can both access PRA information and modify the information to assess the impact these changes may have on plant safety. Both volumes are stand-alone documents; each volume presents several sample computer sessions designed to lead the user through a variety of PRISIM applications used to obtain PRA-related information for monitoring and controlling plant risk.

Research sponsored by U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

*JBF Associates, Inc., Knoxville, TN.

4.92

RISK ASSOCIATED WITH OPERATION OF THE OAK RIDGE NATIONAL LABORATORY HIGH FLUX ISOTOPE REACTOR (HFIR)

G. F. Flanagan D. Johnson*
D. Buttemer* S. Kaplan*

(Abstract of paper presented at the Society for Risk Analysis Annual Meeting, Washington, DC, October 31–November 2, 1988 and at the International Symposium on Research Reactor Safety, Operations and Modifications, Canada, October 23–27, 1989)

A level 1 Probabilistic Risk Assessment (PRA), excluding external events, was performed on HFIR. This was the first PRA on a Department of Energy research reactor. Several unique features of HFIR resulted in new initiating events not found in the standard commercial nuclear reactor. Most of these events involved core flow blockages and fuel manufacturing and inspection errors. Innovative techniques were developed to quantify these sequences. As a result of the PRA calculations, changes were made in the HFIR design and operating procedures which resulted in increased confidence in the safety of the reactor. The HFIR PRA has provided a quantitative framework for making risk based management decisions for future (post restart) design modifications.

Research sponsored by U.S. Department of Energy.

*Pickard, Lowe and Garrick, Inc., Newport Beach, CA.

4.93

USE OF RISK ANALYSIS RESULTS IN SUPPORT OF THE FINAL PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT FOR THE DISPOSAL OF THE U.S. CHEMICAL WEAPONS STOCKPILE

G. F. Flanagan S. Carnes*

(Abstract of paper presented at the National Meeting of the American Institute of Chemical Engineers, Denver, CO, August 22–26, 1988)

Risks associated with the disposal of the U.S. Chemical Weapons Stockpile were a major input

into the selection of the programmatic environmentally preferred alternative as stated in the objectives of the President's Council on Environmental Quality regulations implementing the National Environmental Policy Act (NEPA). The alternatives considered were presented. Five measures of risk were used in the comparison of alternatives. Several risk mitigation measures were identified and the U.S. Army agreed to implement several of these. The final comparison between alternatives are presented in the paper. The no-action alternative posed the largest risk for all the five risk measures. The on-site disposal alternative and the regional disposal alternative resulted in the least risk for all the risk measures when all the uncertainties are included.

In addition to the overall programmatic risk, risks associated with each alternative at each site are presented. In this case, the continued storage (no-action) alternative still results in the largest risk for all the risk measures. However, the on-site disposal alternative does not necessarily result in the lowest risk of the possible alternatives for all sites if the uncertainty in the analysis is considered.

Other factors, in addition to the risks to human health, had to be considered in making the final selection of an environmentally preferred alternative. These factors, the logic arguments used, and methodology developed were described.

Research sponsored by U.S. Army Program for Chemical Munitions.

*Energy Division.

4.94

RISK ASSOCIATED WITH THE DEMILITARIZATION OF THE UNITED STATES CHEMICAL WEAPONS STOCKPILE

G. F. Flanagan W. E. Fraize*
T. Kartachak†

(Abstract of *Reliability Engineering and System Safety* (in press); and also paper presented at the Society for Risk Analysis Annual Meeting, Washington, DC, October 31-November 2, 1988 and at the Air Pollution and Waste Management Control Association 82nd Annual Meeting and Exhibition, Anaheim, CA, June 25-30, 1989)

A full scope probabilistic risk assessment was performed in order to determine the public risk associated with the congressionally mandated unitary chemical weapons demilitarization program.

The method to be used for destruction of the chemical agents is high temperature incineration. The risk assessment was specifically used to assist in determining if any environmentally preferred alternative existed as defined by regulations implementing the National Environmental Policy Act. The alternatives examined included the construction and operation of a single national incinerator with agent shipped by rail, two regional incinerators with rail transportation of agent, eight on-site incinerators located at the current eight U.S. Army depot storage locations, and the no action alternative defined for this study as continued storage for 25 years. Accidents resulting from handling, transportation, and plant operations, as well as, those resulting from external events were considered. Several measures of risk were analyzed and innovative methods of displaying the results to the general public were used in the final reports. Results indicated that the continued storage alternative presented the largest risk with the on-site incineration alternative presenting the least risk. Expected fatalities ranged from greater than 10^{-2} /yr for the continued storage alternative to less than 10^{-4} /yr for the on-site disposal alternatives. Maximum fatalities were greater than 10,000 for the continued storage alternative at some sites.

As a result of the risk assessment and the low likelihood for successful response to accidents occurring off-site, the on-site incineration alternative was selected as the environmentally preferred alternative.

Research sponsored by U.S. Army.

*MITRE Corp., McLean, VA.

†U.S. Army, Aberdeen, MD.

4.95

THE PROBABILISTIC TREATMENT OF POTENTIAL ACCIDENTS: HOW, HOW MUCH, AND HOW OFTEN COULD CHEMICAL AGENT BE RELEASED TO THE BIOSPHERE?

W. E. Fraize* G. F. Flanagan

(Abstract of *Environmental Professional* (in press))

The rationale for, and the approach used in, the risk analysis of the Army's Chemical Stockpile Disposal Program (CSDP) is described. The

paper discusses the major features of the CSDP that affected the design of the risk analysis, principal among which are the wide range of potentially risky activities, the use of multiple sites connected by transportation corridors, the low probability - high consequence nature of most hazards, the lack of a historical data base of actual accidents involving chemical agent release, and the presence of energetic materials (explosives) in conjunction with the chemical agent. The importance of communicating the results of the risk analysis to a broad audience spectrum and the impact those considerations had on the choice of risk measures and the way they were portrayed is described.

Research sponsored by U.S. Department of Energy.

*Mitre Corporation, Mclean, VA.

4.96

A REVISIT TO THE PASSIVELY-SAFE REACTORS

D. L. Moses

(Abstract of oral presentation presented to the Chattanooga Engineers Club, Chattanooga, TN, August 28, 1989)

International activity in the development of passively-safe reactors is reviewed over the past two years. Reactor options and their development status are noted.

Research sponsored by U.S. Department of Energy.

Section 5

**ENGINEERING PHYSICS AND MATHEMATICS
INFORMATION CENTERS**

5.0. INTRODUCTION

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, October 1, 1987 - August 31, 1989. 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 1978 to perform various tasks in support of Nuclear Regulatory Commission (NRC) programs in technical data management and computer code development, standardization and maintenance. Residual tasks started within TDMC were completed during FY 1988.

Radiation Shielding Information Center (RSIC)

During this reporting period, RSIC continues to be widely used as attested by current user statistics. Usage reported at the end of FY 1989 showed that the total number of requests processed during the year (3419) exceeded those in FY 1988 (3244) by 5%. The statistics indicate that the individual user is requesting more products and/or services; activities required to fill the requests increased by 4% (12,660 vs 12,194). The increased usage is largely attributed to waste management and defense-related programs.

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 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 of particular techniques, especially computer-based techniques for solving radiation transport or nuclear data problems; helping to establish shielding benchmark problems and shielding standards; providing bibliographic information; and generally providing problem assistance to requesters. Staff members also engage in radiation transport developments and perform radiation transport studies, often in collaboration with staff members in EPMD as well as other institutions.

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 (computer codes, technical advice, bibliographic and other data,) 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. During the reporting period, broad-group cross-section libraries for fast reactor

shielding (VELM61 and VELM22) and defense applications (DABL69) were derived from VITAMIN-E and made available through RSIC.

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 816 computer code packages and 146 data packages. The RSIC Newsletter is currently mailed monthly to 1650 people. A total of 98 persons (22 foreign, 76 domestic) came during the reporting period for an orientation visit and /or to use the center's facilities, an average of 49 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 23,000 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 184 transmissions of technology as follows: 80 new computer codes and data libraries; 20 replacements of existing code/data packages with newly-frozen versions; 20 new hardware versions or other extensions to existing code/data packages; 39 updates to improve existing code/data packages; and 25 corrections to fix errors in existing code/data packages.

Announcement of availability was made for 141 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 1978 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. All tasks assigned by the contract monitor in FY 1987 were completed.

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 NIST 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 the 1988 data base as a data library. A report of the compilation effort, including discussion of the technical issues and the draft standard, has been published as ORNL/RSIC-49.

When the new photon cross section library PHOTX became available, the Japanese collaborators recalculated the buildup factors for the elements molybdenum to uranium. They gave careful attention to the behavior near the K edge where the buildup factors become extremely large. The latest draft of the standard also includes correction factors to compensate for the neglect of coherent scattering based on calculations of collaborators in India. Coefficients for the Taylor buildup factor function have recently been published in WAPD-TM-1628. A selection of the data will be made on the basis of sufficient accuracy to include in the standard. The final draft is expected to be released for ANS-6 approval in early 1990.

RADIATION TRANSPORT DEVELOPMENTS

5.1

DISCRETE ANGLE BIASING IN MONTE CARLO RADIATION TRANSPORT

S. N. Cramer

(Abstract of ORNL/RSIC-50, May 1988)

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 code 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

ANALYTIC SOLUTION OF A FIVE-DIRECTION RADIATION TRANSPORT MODEL

S. N. Cramer

(Abstract of *Trans. Am. Nucl. Soc.* 57, 232 (1988))

To test certain spatial and angular-dependent Monte Carlo biasing techniques, a one-dimensional, one-energy, two-media, five-direction radiation transport model has been devised for which an analytic solution exists. Although this solution is too long to be conveniently expressed in an explicit form, it can be easily evaluated on the smallest of computers. The salient features of the solution are that it involves only a 4×4 determinant, a quadratic equation, and two sets of four linear algebraic equations. The Monte Carlo simulation of this transport model is very simple and also applicable to small computers. This model gives an analyst the ability to test certain features

of biasing techniques and code generation of biasing parameters, involving directional dependence and changes in cross-section media through many mean-free-paths of particle penetration. The comparison of results with an exact solution eliminates many of the uncertainties and most of the expense associated with the solution of realistic calculations using general Monte Carlo codes on main-frame computers.

Research sponsored by U.S. DOE Office of Magnetic Fusion Energy.

5.3

HYPERCUBE APPLICATIONS OF THE xy GEOMETRY NODAL METHOD FOR THE NEUTRON DIFFUSION EQUATION

B. L. Kirk Y. Y. Asmy

(Abstract of *Trans. Am. Nucl. Soc.* 57, 104 (1988))

Solving the one-group neutron diffusion equation by the nodal method requires finding the solution of a system of three equations: the x - and y -current continuity and the conservation equations. This requires matrix inversion. For a very coarse mesh size, the solution may take only a few seconds. As the mesh gets finer, the system of equations grows in the number of unknowns resulting in a matrix of very high order. On serial computers, matrix inversion is limited by the amount of memory. The CPU time for large systems of equations can also become prohibitive. Thus, a new parallelized iterative algorithm is developed.

We have derived and tested an algorithm that is truly parallel, but its application on the hypercube is greatly restrained by message passing. Our results suggest that there is an upper limit on the number of processors that may be used on hypercube. It follows that extremely large speedups characteristic of hypercube implementation cannot be expected and that relatively low efficiencies are produced unless very large problems ($M \sim 100$) are solved. It may be that parallel processors with shared memory are more suitable for the problem.

Research sponsored by U.S. DOE Office of Magnetic Fusion Energy.

5.4

AN ITERATIVE PROCEDURE FOR SOLVING THE NODAL METHOD NEUTRON DIFFUSION EQUATION ON A PARALLEL PROCESSOR

B. L. Kirk Y. Y. Asmy

(Abstract of oral presentation given at the SIAM Conference on Applied Linear Algebra, Minneapolis, MN, July 11-15, 1988)

Nodal methods have been shown to be a powerful computational tool in solving the neutron diffusion equation. Solving the nodal equations using matrix inversion subroutines heavily taxes the computer on memory and CPU time, even for relatively coarse meshes. We derive an iterative procedure that iterates on the cell-averaged and the cell-surface fluxes. In each iteration, we solve a set of tridiagonal matrix equations representing rows or columns of computational cells. Since these are uncoupled, they can be solved in parallel. We solved a test problem and compared the required CPU time using DGTSL (LINPACK) and the new iterative method. For all meshes finer than 12×12 the latter required shorter CPU time than the former; for example, on an 18×18 mesh 696.4 and 1609.9 s were required, respectively. In addition, the inversion method for a 20×20 mesh (matrix order 1160) requires storage of about 1.4 MW, possibly exceeding the capacity of a serial computer. The same computer can solve much finer meshes with our scheme.

Research sponsored by U.S. Department of Energy.

5.5

A PARALLEL APPROACH TO THE NODAL METHOD SOLUTION OF THE TWO-DIMENSIONAL DIFFUSION EQUATION

B. L. Kirk Y. Y. Asmy

(Abstract of paper presented at the American Nuclear Society Topical Meeting on Advances in Nuclear Engineering, Computation, and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 1, pp. 23:1-23:12 (1989))

The neutron diffusion equation in two-dimensional geometry is solved using the nodal method formalism. Three systems of equations arise in

the solution: the x -current continuity equations, the y -current continuity equations, and the balance of neutrons equations. An iterative procedure is developed to solve for the surface fluxes and cell-averaged fluxes by de-coupling the set of balance equations from the two current continuity systems. The iteration is initiated in the balance equation which supplies the starting estimates of the cell-averaged fluxes. These estimates are fed into the uncoupled, tridiagonal sets of x -current and y -current equations which can be solved independently of each other, so that the surface fluxes can be computed. The resulting surface fluxes are substituted into the balance equations to update the cell-averaged fluxes. These updated values become the new iterates.

The independent nature of the x - and y -current continuity equations becomes the focal point of parallelism. The algorithm is implemented on two types of parallel machines—the Intel iPSC/2 hypercube which belongs to the class of distributed memory processors, and the Sequent balance 8000 which is a shared memory computer. Results indicate the algorithm to be better suited for a shared memory environment.

Research sponsored by U.S. DOE Office of Fusion Energy.

5.6

NEW GAMMA-RAY BUILDUP FACTOR DATA FOR POINT KERNEL CALCULATIONS: ANS-6.4.3 STANDARD REFERENCE DATA

D. K. Trubey

(Abstract of ORNL/RSIC-49, September 1988)

An American Nuclear Society Standards Committee Working Group, identified as ANS-6.4.3, has developed a set of evaluated gamma-ray isotropic point-source buildup factors and attenuation coefficients for a standard reference data base. The 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. Additional buildup factor data were obtained from PALLAS code results. Attention has been given to frequently neglected processes such as bremsstrahlung and the effect of introducing a

tissue phantom behind the shield. The proposed draft standard, provided as an appendix, contains data for a source energy range from 15 keV to 15 MeV and for 23 elements and 3 mixtures (water, air, and concrete). The buildup factor data are

also represented as coefficients for the G-P fitting function. Tables giving correction factors for multiple scattering in tissue are also provided.

Research sponsored by Nuclear Regulatory Commission, Office of Administration and Resources Management.

RADIATION TRANSPORT STUDIES

5.7

THE EFFECT OF COHERENT SCATTERING IN PHOTON RADIATION TRANSPORT CALCULATIONS

S. N. Cramer B. L. Kirk
J. Broadway*

(Abstract of ORNL/RSIC-51, April 1989)

The effect of including or excluding the coherent scattering cross section in the Monte Carlo analysis of photon penetration in water has been studied. Source energies from 80 keV down to 20 keV were investigated. The inclusion of coherent scattering has the effect of degrading the photon population with depth of penetration, but at the same time dispersing the population over a larger volume than when it is excluded from the scattering model.

Research sponsored by U. S. Environmental Protection Agency, Office of Radiation Programs.

*U.S. Environmental Protection Agency, Montgomery, AL.

5.8

NEUTRON STREAMING BENCHMARK CALCULATIONS

T. Y. Lee* S. N. Cramer

(Abstract of ORNL/RSIC-52, August 1989)

Computational techniques used to analyze neutron streaming through cavities and ducts are described. The configurations are simplified geometries of streaming paths which can be found in nuclear fission and fusion reactors. The results obtained using available computational tools are compared to each other.

Research sponsored by U.S. DOE Office of Nuclear Energy.

*Korea Atomic Energy Research Institute, Seoul, Korea.

INFORMATION ANALYSIS CENTER ACTIVITIES

5.9

NUCLEAR INDUSTRY QUALITY, PRODUCTIVITY, AND INNOVATION FROM THE PERSPECTIVE OF AN INTERNATIONAL INFORMATION CENTER

B. F. Maskewitz

(Abstract of oral presentation given at the Annual Congress of the South African Association of Physicians in Medicine and Biology, Cape Town, Africa, March 2-4, 1988)

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.

The 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

TECHNOLOGY RESOURCES IN SUPPORT OF PROGRAMS OF THE PHYSICIST IN MEDICINE AND BIOLOGY

B. F. Maskewitz

(Abstract of oral presentation given at the Annual Congress of the South African Association of Physicists in Medicine and Biology, Cape Town, Africa, March 2-4, 1988)

This paper will present a brief overview of methodology in use in USA energy research and development programs for radiation protection and other aspects of health physics. It will also cover some aspects of biomedical computing with emphasis on quality assurance.

A discussion of cooperative efforts to advance the state of the art in radiation protection, transport, and shielding will be included in the presentation. Technology resources (literature, computer codes, data libraries, etc.) available from the Radiation Shielding Information Center (RSIC) for use in research areas covered in the 28th SAAPMB Congress will be emphasized.

Research sponsored by U.S. Department of Energy.

5.11

COMPUTERS AND INTERACTIONS BETWEEN PHYSICIANS AND HEALTH PHYSICISTS

B. F. Maskewitz

(Abstract of oral presentation given at the Summer School on Computers in Medical Research, South African Medical Research Council, Cape Town, Africa, February 29-March 1, 1988)

Interaction of the physician and the health physicist within the medical biophysics community of the United States (USA) is, in general, often cooperative and sometimes collaborative. It is also complimentary, with the health physicist in a research environment formatting his research results to facilitate usage in the physician's domain, often in the form of computer-readable data. The interaction of the physician and the medical physicist, especially in nuclear medicine areas, is relational, collaborative, and supportive. The use of computers in clinical applications often implies a partnership of physician and medical physicist and

a mutually supportive interaction between physician and health physicist.

This paper will examine interactions above as related to the use of computers, with emphasis on activities in nuclear medicine. Related technical information and computing technology resources produced by health physicists and other scientists in support of medical and biophysics research will be cited. Computer usage for other medical applications will be briefly reviewed from the aspect of software systems.

The experiences of the Society of Nuclear Medicine (SNM) in the U.S.A. (membership including physicians, medical physicists, health physicists, radiologists, etc. in which the Society seeks to strengthen the interactions within its varied membership for a unified effort to advance the state of the art in the effective use of computers in clinical and other medical applications will be explored. Related parallel efforts of the American Society for Computer Medicine (SCM) will also be briefly reviewed.

Conclusions will be drawn concerning the success/failure of the experimental efforts described and the current state of the art will be briefly summarized.

Research sponsored by U.S. Department of Energy.

5.12

METHODS AND FORMATS FOR ENDF/B-VI

R. W. Roussin

(Abstract of *Trans. Am. Nucl. Soc.* 60, 617 (1989))

The formats for ENDF/B-VI have been dramatically revised (though Version V formats had been extremely resistant to change). These changes are due to the recognition of some inherent limitations in the format in terms of providing a true representation of the physics of interaction of particles with matter.

The format manual, "Data Formats and Procedures for the Evaluated Nuclear Data File, ENDF" has been completely rewritten and the final version is expected to be issued during 1989. Draft copies are available to evaluators and potential processors of ENDF/B-VI. The new format, designated ENDF-6, allows higher incident energies, adds more complete descriptions of the distributions of emitted particles, and provides for

incident charged particles and photons by partitioning the ENDF library into sublibraries. Decay data, fission product yield data, thermal neutron scattering data, and photo-atomic data have also been formally placed in sublibraries. Representations of the resonance region via R-function and R-matrix have been introduced and emitted-particle-correlated energy-angle distributions are allowed. Covariance formats for secondary distributions and isomer production are provided.

Research sponsored by U.S. DOE Office of Fusion Energy and Defense Nuclear Agency.

5.13

THE STATUS OF ENDF/B-VI

R. Roussin C. Dunford*
R. McKnight† P. Young‡

[Abstract of paper presented at the 7th International Conference on Radiation Shielding, Bournemouth, UK, September 12-16, 1988; Proc. Vol. III, pp. 1125-1134 (1989)]

A new version of the United States evaluated nuclear data file, ENDF/B-VI, is presently under development. Major emphasis is being placed on correcting some long-standing nuclear data problems that adversely affect applied calculations for both fission and fusion reactors. The paper reviews modifications to the formats and utility codes, outline the evaluation activities, discusses the data testing programs, and projects a date for the unrestricted release of the new library.

Research sponsored by Defense Nuclear Agency and U.S. DOE Office of Fusion Energy.

*Brookhaven National Laboratory, Upton, NY.

†Argonne National Laboratory, Argonne, IL.

‡Los Alamos National Laboratory, Los Alamos, NM.

5.14

RSIC AFTER 25 YEARS —
CHALLENGES AND OPPORTUNITIES

R. W. Roussin B. F. Maskewitz
D. K. Trubey

[Abstract of paper presented at the 7th International Conference on Radiation Shielding, Bournemouth, UK, September 12-16, 1988; Proc. Vol. III, pp. 1135-1142 (1989)]

The Radiation Shielding Information Center (RSIC) observed its 25th year in operation in 1987. During that time numerous changes have occurred in the government programs that sponsor RSIC and in the radiation transport community which it serves. The continued need for RSIC is evident from the steady volume of requests and interactions with the user community. It is a continual challenge to adjust and adapt our operation to respond to the demands placed on RSIC by sponsors and users. Cooperation between sponsors, users, and the RSIC staff is the key to keeping RSIC as the focus of activities in the international radiation transport community.

Research sponsored by U.S. DOE Office of Fusion Energy.

5.15

AN OVERVIEW OF THE
RADIATION SHIELDING
INFORMATION CENTER
(RSIC)

D. K. Trubey

[Abstract of *Health Physics* 57(3), 497-498 (1989)]

The Radiation Shielding Information Center (RSIC) at Oak Ridge National Laboratory, as an integral part of its information analysis activities, collects, makes operable packages, and distributes computer code software and data packages to nuclear engineering and health physicists engaged in shielding design or dose calculations. The various codes are designed for calculations related to radiation from reactors, radioisotopes, weapons and accelerators and to radiation occurring in space. The Center uses the word "package" to mean all the items needed to utilize a code effectively. The package normally includes documentation describing the theory and code operation (contributor's report plus RSIC abstract and notes) and one or more reels of tape or diskettes on which is written

the source program, operating program, input and output for a sample problem, data libraries, and auxiliary routines. Though most of the software and data are contributed to RSIC by its user com-

munity, the Center does some software development and has been very actively involved in data library generation for user applications.

Research sponsored by U.S. Department of Energy.

TRANSFER OF COMPUTING TECHNOLOGY

5.16

PHOTON CROSS SECTIONS FOR ENDF/B-VI

D. K. Trubey M. J. Berger*
J. H. Hubbell*

[Abstract of paper presented at the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Reaction Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vol. 1, pp. 18-1-18-12 (1989)]

The PHOTX library of the National Institute of Standards and Technology will be used as the basis of File 23 (photon cross sections) for ENDF/B-VI. The PHOTX library is based on an experimental data base consisting of 21,000 data points from 512 literature sources for 82 elements. An important difference from earlier compilations is that renormalization of photo-effect cross sections is not performed.

Research sponsored by U.S. DOE Office of Fusion Energy.

*National Institute of Standards and Technology, Gaithersburg, MD.

5.17

GUIDE FOR LICENSING EVALUATIONS USING CRAC2: A COMPUTER PROGRAM FOR CALCULATING REACTOR ACCIDENT CONSEQUENCES

J. E. White R. W. Roussin
H. Gilpin*

(Abstract of ORNL/TDMC-3, NUREG/CR-5264, December 1988)

A version of the CRAC2 computer code applicable for use in analyses of consequences and risks of reactor accidents in case work for environmental statements has been implemented for use on the Nuclear Regulatory Commission

Data General MV/8000 computer system. Input preparation is facilitated through the use of an interactive computer program which operates on an IBM personal computer. The resulting CRAC2 input deck is transmitted to the MV/8000 by using an error-free file transfer mechanism. To facilitate the use of CRAC2 at NRC, relevant background material on input requirements and model descriptions has been extracted from four reports - "Calculations of Reactor Accident Consequences," Version 2 NUREG/CR-2326 (SAND81-1994) and "CRAC2 Model Descriptions," NUREG/CR-2552 (SAND82-0342), "CRAC Calculations for Accident Sections of Environmental Statements," NUREG/CR-2901 (SAND82-1693), and "Sensitivity and Uncertainty Studies of the CRAC2 Computer Code," NUREG/CR-4038 (ORNL-6114). When this background information is combined with instructions on the input processor, this report provides a self-contained guide for preparing CRAC2 input data with a specific orientation toward applications on the MV/8000.

Research sponsored by Nuclear Regulatory Commission.

*NRC Summer Student.

5.18

SUSD: A COMPUTER CODE FOR CROSS-SECTION SENSITIVITY AND UNCERTAINTY ANALYSIS INCLUDING SECONDARY NEUTRON ENERGY AND ANGULAR DISTRIBUTIONS

K. Furuta* Y. Oka*
S. Kondo*

(Abstract of ORNL/TR-88/18, November 1988)

A cross-section sensitivity-uncertainty analysis code SUSD has been developed. This code calculates sensitivity coefficients for one- and two-

dimensional transport problems based on the first order perturbation theory. Variance and standard deviation of detector responses or design parameters can be obtained using cross-section covariance matrices. In neutron transport problems this code is able to perform sensitivity-uncertainty analyses for secondary angular distribution (SAD) or sec-

ondary energy distribution (SED). Some peripheral programs, which prepare cross-section data necessary for the SUSD code, also have been developed, and they are described in this report.

Research sponsored by U.S. DOE Office of Fusion Energy.

*University of Tokyo, Tokyo, Japan.

APPENDICES

PERSONNEL CHANGES

NEW STAFF MEMBERS

A. Scientific Staff

C. C. Brandt, University of Tennessee, Knoxville, Tennessee
R. E. Flanery, Jr., University of Tennessee, Knoxville, Tennessee
J. A. Green, Tennessee Technological University, Cookeville, Tennessee
M. R. Leuze, Duke University, Durham, North Carolina
P. J. Otaduy, University of Florida, Gainesville, Florida
J. V. Pace III, Mississippi State University, Mississippi State, Mississippi
B. W. Peyton, Clemson University, Clemson, South Carolina
D. E. Pierce, Tennessee Technological University, Cookeville, Tennessee
J. T. Robinson, Massachusetts Institute of Technology, Cambridge, Massachusetts
F. J. Sweeney, University of Tennessee, Knoxville, Tennessee

B. Administrative and Technical Support Staff

V. M. Cauley (transferred from Environmental & Health Protection Division)
C. R. Kidwell (transferred from Publications Division)
R. A. Lexvold (co-op)
G. D. Oliver (co-op)
J. L. Painter (co-op)
M. D. Russell (co-op)
A. L. VanHull (co-op)
D. H. Wood (co-op)

STAFF TRANSFERS OUT AND TERMINATIONS

A. Scientific Staff

J. Barhen (other employment)
B. L. Burks (transferred to Central Management Offices)
D. G. Cacuci (other employment)
Y. H. Etheridge (other employment)
G. F. Flanagan (transferred to Research Reactors Division)
M. Goldstein (completion of assignment)
E. C. Halbert (transferred to Physics Division)
D. L. Henderson (other employment)
C. C. Jorgensen (other employment)
J. J. Manning (retired)
B. F. Maskewitz (retired)
D. L. Moses (transferred to Engineering Technology Division)
J. T. Robinson (transferred to Instrumentation & Controls Division)
L. E. Parker (leave of absence)
D. L. Selby (transferred to Central Management Organization)
A. D. Solomon (other employment)
N. Sreenath (other employment)
E. Wacholder (completion of assignment)
C. R. Weisbin (other employment)

B. Administrative and Technical Support Staff

N. S. Currence (transferred to Health and Safety Research Division)
 A. B. Gustin (retirement)
 B. L. Humphrys (completed co-op assignment)
 J. K. Ingersoll (other employment)
 S. E. Johnston (completed co-op assignment)
 D. M. Jolley (completed co-op assignment)
 K. H. Koger (completed co-op assignment)
 M. W. Nay (other employment)
 G. D. Oliver (completed co-op assignment)
 J. J. Roberts (completed co-op assignment)
 M. D. Russell (completed co-op assignment)
 C. H. Zeigler (transferred to Solid State Division)

DISTINGUISHED SCIENTISTS

J. J. Dongarra, Distinguished Scientists Program, University of Tennessee/ORNL
 J. A. George, Distinguished Scientists Program, University of Tennessee/ORNL

GUESTS AND SHORT-TERM APPOINTMENTS**University/Industry Research Collaborators or Consultants****A. Scientific Staff**

J. Barlow, Penn State University, University Park, Pennsylvania
 G. L. Bilbro, North Carolina State University, Raleigh, North Carolina
 J. R. S. Blair, University of Tennessee, Knoxville, Tennessee
 W. J. Book, Oklahoma State University, Stillwater, Oklahoma
 C. L. Bowman, Ball Systems Engineering Division, San Diego, California
 C. R. Bovell, Physics Applications, Inc., Hixson, Tennessee
 D. G. Cacuci, University of California-Santa Barbara, Santa Barbara, California
 B. W. Char, University of Tennessee, Knoxville, Tennessee
 K. Chatani, PNC, Japan
 G. C. Cosner, Self-employed, Miami, Florida
 A. Cossic, CEA - CEN/Saclay, France
 B. Coury, University of Massachusetts, Amherst, Massachusetts
 G. J. Davis, Georgia State University, Atlanta, Georgia
 E. Deplane, Massachusetts Institute of Technology, Cambridge, Massachusetts
 H. Derrien, CEN, Cadarache, France
 J. J. Dornig, University of Virginia, Charlottesville, Virginia
 R. E. Funderlic, North Carolina State University
 J. B. Fussell, JBF Associates, Knoxville, Tennessee
 G. H. Gokub, Stanford University, Stanford, California
 P. Haas, Concord Associates, Inc., Knoxville, Tennessee
 K. F. Hansen, Massachusetts Institute of Technology, Cambridge, Massachusetts
 R. M. Haralick, University of Washington, Seattle, Washington
 E. Heer, Heer Associates, LaCanada, California
 S. S. Iyengar, Louisiana State, Baton Rouge, Louisiana
 C. M. Jensen, University of Oklahoma, Norman, Oklahoma
 M. S. Jones, Virginia Polytechnic Institute & State University, Blacksburg, Virginia
 O. A. Karakashian, O. A., University of Tennessee, Knoxville, Tennessee
 F. Kertesz, Self-employed, Oak Ridge, Tennessee

D. Kincaid, University of Texas, Austin, Texas
 A. I. Khuri, University of Florida, Gainesville, Florida
 T-Y. Lee, Korea Advanced Energy Research Institute, South Korea
 J. E. Leiss, Self-Employed, Gaithersburg, Maryland
 M. R. Lauze, Vanderbilt University, Nashville, Tennessee
 J. W. H. Liu, York University, Toronto, Ontario
 B. J. MacLennar, University of Tennessee, Knoxville, Tennessee
 B. F. Maskewitz, Self-employed, Knoxville, Tennessee
 N. Moray, University of Illinois, Urbana, Illinois
 M. C. Moxon, UKAEA, AERE-Harwell, Oxon, England
 D. C. Mutchler, University of Tennessee, Knoxville, Tennessee
 B. Newnam, Los Alamos National Laboratory, Los Alamos, New Mexico
 B. Oldham, Texas Technical University, Lubbock, Texas
 J. Ortega, University of Virginia, Charlottesville, Virginia
 N. Ohtani, PNC, Japan
 J. F. Palmer, Oklahoma State University, Stillwater, Oklahoma
 S. Pflanczer, Science & Technology, Inc., Oak Ridge, Tennessee
 H. E. Pople, Oklahoma State University, Stillwater, Oklahoma
 M. J. Rabins, Oklahoma State University, Stillwater, Oklahoma
 M. Rahman, Bangladesh Atomic Energy Commission
 N. Rao, Old Dominion University, Norfolk, Virginia
 K. N. Reid, Oklahoma State University, Stillwater, Oklahoma
 J. P. Reihls, Technische Universität Wien, Karlsplatz, Austria
 H-J. Schmiedmayer, Technische Universität Wien, Karlsplatz, Austria
 S. Serbin, University of Tennessee, Knoxville, Tennessee
 K. Setoguchi, PNC, Japan
 L. R. Shenton, University of Georgia, Athens, Georgia
 K. Shibata, Japan Atomic Energy Research Institute, Tokai-Mura, Japan
 W. E. Snyder, North Carolina State University, Raleigh, North Carolina
 A. D. Solomon, Self-employed, Omer, Israel
 C. A. Sparrow, Mississippi State University, Mississippi State, Mississippi
 D. Steiner, Rensselaer Polytechnic Institute, Troy, New York
 R. Stohler, Kaman Science Corporation, Albuquerque, New Mexico
 S. Stojanovic, University of Cincinnati, Cincinnati, Ohio
 K. Storzjohann, Deutsche Forschungsgemeinschaft, Mainz, West Germany
 J. B. Svirsky, University of Tennessee, Knoxville, Tennessee
 M. Thompson, University of Tennessee, Knoxville, Tennessee
 T. Toffoli, Massachusetts Institute of Technology, Cambridge, Massachusetts
 S. L. Tosunoglu, University of Texas at Austin, Austin, Texas
 I. Treitler, University of Tennessee, Knoxville, Tennessee
 B. W. Turnbull, Cornell University, Ithaca, New York
 G. G. Vining, University of Florida, Gainesville, Florida
 M. Vose, University of Tennessee, Knoxville, Tennessee
 E. L. Wachspress, University of Tennessee, Knoxville, Tennessee
 H. Watanabe, University of North Carolina-Chapel Hill, Chapel Hill, North Carolina
 M. F. Wheeler, University of Houston, Houston, Texas
 M. A. Williams, IBM, Kingston, New York
 M. L. Williams, Louisiana State University, Baton Rouge, Louisiana
 R. R. Yager, Self-employed, New York, New York

B. Technical Support

L. S. Abbott, Tec-Com Company, Knoxville, Tennessee
 J. A. Etheridge, Roanoke College, Salem, Virginia
 F. B. Hedspeth, University of Tennessee, Knoxville, Tennessee
 H. P. Hiriyanaiyah, North Carolina State University, Raleigh, North Carolina
 B. L. Humphrys, University of Tennessee, Knoxville, Tennessee
 D. M. Jollay, University of Tennessee, Knoxville, Tennessee
 P. Rusu, University of Colorado, Boulder, Colorado
 P. L. Stanfield, University of Kentucky, Lexington, Kentucky

C. Graduate Students

M. H. Abu-Shehadeh, University of Tennessee, Knoxville, Tennessee
 M. E. Bradley, University of Virginia, Charlottesville, Virginia
 G. L. Cacuci, University of Tennessee, Knoxville, Tennessee
 C-X. Chen, University of Tennessee, Knoxville, Tennessee
 H. I. Christensen, Aalborg University, Aalborg, Denmark
 E. Chu, University of Waterloo, Waterloo, Ontario, Canada
 J. A. Davis, University of Tennessee, Knoxville, Tennessee
 H. D. Embrechts, Katholieke Universiteit, Leuven, Belgium
 R. E. England, University of Tennessee, Knoxville, Tennessee
 K. Gates, University of Washington, Seattle, Washington
 J. A. George, University of Tennessee, Knoxville, Tennessee
 L. M. T. Gomes, University of Tennessee, Knoxville, Tennessee
 J. Graham, Louisiana State University, Baton Rouge, Louisiana
 P. A. Graham, Louisiana State University, Baton Rouge, Louisiana
 E. S. Groton, University of Tennessee, Knoxville, Tennessee
 S. Gulati, Louisiana State University, Baton Rouge, Louisiana
 D. Hartley, University of Tennessee, Knoxville, Tennessee
 V. G. Hedge, Louisiana State University, Baton Rouge, Louisiana
 C. S. Henkel, North Carolina State University, Raleigh, North Carolina
 L. C. Leal, University of Tennessee, Knoxville, Tennessee
 R. L. Macklin, University of Tennessee, Knoxville, Tennessee
 C. March-Leuba, University of Tennessee, Knoxville, Tennessee
 L. S. Ostrouchov, University of Tennessee, Knoxville, Tennessee
 L. E. Palko, University of Tennessee, Knoxville, Tennessee
 N. Rao, Louisiana State University, Baton Rouge, Louisiana
 A. S. Sabharwal, Louisiana State University, Baton Rouge, Louisiana
 R. S. Sawhney, University of Tennessee, Knoxville, Tennessee
 R. C. Thornton, Old Dominion University, Norfolk, Virginia
 A. K. VanCleave, University of Tennessee, Knoxville, Tennessee

D. Great Lakes College Association Faculty Research Participation

D. S. Christiansen, Albion College, Albion, Michigan
 R. R. Winters, Denison University, Granville, Ohio

E. Great Lakes College Association Science Semester Program

T. S. Attari, Denison University, Granville, Ohio
 S. S. Khawaja, Coe College, Cedar Rapids, Iowa

F. Oak Ridge Associated Universities - Faculty Research Participants

K. Bowyer, University of South Florida, Tampa, Florida
 J. C. Courtney, Louisiana State University, Baton Rouge, Louisiana
 G. J. Davis, Georgia State University, Atlanta, Georgia
 H. N. Narang, Tuskegee University, Auburn, Alabama
 D. A. Poplawski, Michigan Technological University, Houghton, Michigan
 A. Roy, Arizona State University, Tempe, Arizona
 K. Sigmon, University of Florida, Gainesville, Florida
 P. F. Spelt, Wabash College, Crawfordsville, Indiana
 C. W. Steidley, Central Washington University, Ellensburg, Washington
 V. S. Sunderam, Emory University, Atlanta, Georgia
 S. Thompson, Radford University, Radford, Virginia

G. Oak Ridge Associated Universities - Post-Doctoral Program

P. F. R. Belmans, Institut National de Recherche en Informatique et en Atomique, Creil, France
 J-C. Culioli, Schlumberger Montrouge Research, Paris, France
 J. H. Han, University of Maryland, College Park, Maryland
 N. Toomarian, Technion, Israel

H. Oak Ridge Associated Universities - Undergraduate Research Participants

D. P. Katzman, University of Pennsylvania, Philadelphia, Pennsylvania
 J. L. Painter, East Tennessee State University, Johnson City, Tennessee

I. Oak Ridge Associated Universities - Science and Engineering Research Semester

T. K. Arledge, Ohio Northern University, Ada, Ohio
 S. Autommarchi, Florida Atlantic University, Boca Raton, Florida
 L. S. Auvil, Alderson-Broadbent College, Philippi, West Virginia
 V. K. Bansal, Cornell University, Ithaca, New York
 K. A. Barry, Brigham Young University, Provo, Utah
 R. Brunkhorst, Loras College, Dubuque, Iowa
 R. A. Cacheiro, Tennessee Technological University, Cookeville, Tennessee
 S. M. de Rada, Southern Mississippi University, Hattiesburg, Mississippi
 N. D. Drochak, Miami University, Oxford, Ohio
 R. Even, Cornell University, Ithaca, New York
 L. A. Farkas, Cornell University, Ithaca, New York
 M. C. Finley, Transylvania University, Lexington, Kentucky
 G. W. Flake, Clemson University, Clemson, South Carolina
 K. H. Gaiser, Michigan Technological University, Houghton, Michigan
 K. J. Herzog, Northern Illinois University, De Kalb, Illinois
 T. Heywood, University of Florida, Gainesville, Florida
 A. M. Jijina, Illinois Institute of Technology, Chicago, Illinois
 L. J. Kelleher, Ohio Northern University, Ada, Ohio
 K. L. Knight, Meredith College, Raleigh, North Carolina
 C. M. Lawder, Southern Illinois University, Edwardsville, Illinois
 E. Lazaridis, University of Pennsylvania, Philadelphia, Pennsylvania
 I. L. Lough, Rhode Island College, Providence, Rhode Island
 E. S. Lyness, Iowa State University, Ames, Iowa
 M. S. Madanat, Cheyney University of Pennsylvania, Cheyney, Pennsylvania
 K. L. Marrs, University of Missouri-Rolla, Rolla, Missouri
 P. Marquis, Tufts University, Medford, Massachusetts

J. W. Palmer, State University of New York-Buffalo, Buffalo, New York
 R. R. Powell, Allegheny College, Meadville, Pennsylvania
 C. Roe, Loyola University, New Orleans, Louisiana
 J. A. Sandberg, Utah State University, Logan, Utah
 D. L. Sanderson, Lawrence Institute of Technology, Southfield, Michigan
 D. F. Scollan, Pennsylvania State University, University Park, Pennsylvania
 C. M. Sheppard, University of Michigan, Ann Arbor, Michigan
 D. M. Smith, Davis & Elkins College, Elkins, West Virginia
 H-J. Wu, University of California, Los Angeles, California

J. Oak Ridge Associated Universities - Practicum Assignments

S. Epperson, University of Florida, Gainesville, Florida
 J. P. Hannon, University of Virginia, Charlottesville, Virginia
 S. I. Hruska, Jacksonville State University, Jacksonville, Alabama

K. Oak Ridge Associated Universities - Professional Internship Program

J. A. Etheridge, Roanoke College, Salem, Virginia
 M. S. Sillman, University of Missouri-Rolla, Rolla, Missouri

L. DOE Science and Energy Research Semester Program

C. Currin, Bryn Mawr, Bryn Mawr, Pennsylvania
 C. S. Henkel, North Carolina State University, Raleigh, North Carolina
 S. P. Kho, Truman College, Chicago, Illinois
 J. L. King, University of Tennessee, Knoxville, Tennessee
 C. M. Lance, Michigan State University, East Lansing, Michigan
 L. A. Renker, Baldwin-Wallace College, Berea, Ohio

M. Teacher Research Program

L. W. Daniels, Oak Ridge Schools, Oak Ridge, Tennessee
 D. J. Dodd, Haywood County Board of Education, Jackson, Tennessee
 I. J. Meletiou, Knox County School System, Knoxville, Tennessee

N. U.S. Military Service Academy Research Associates

J. A. Dietz, U.S. Naval Academy, Annapolis, Maryland
 J. R. Dundas, U.S. Naval Academy, Annapolis, Maryland
 T. M. Mathis, U.S. Naval Academy, Annapolis, Maryland
 C. A. McGougan, U.S. Military Academy, West Point, New York
 D. McVay, U.S. Military Academy, West Point, New York
 T. E. Slusarchyk, U.S. Naval Academy, Annapolis, Maryland
 G. S. Vanni, U.S. Naval Academy, Annapolis, Maryland

O. Special Program for Gifted High-School Students

D. A. Huff, Oak Ridge High School, Oak Ridge, Tennessee

P. ORNL/UT Special Year on Numerical Linear Algebra

L. Adams, University of Washington, Seattle, Washington
 J. Barlow, Penn State University, University Park, Pennsylvania
 A. Bjorck, Linkoping University, Linkoping, Sweden
 C. Beattie, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
 J. R. Bunch, University of California-San Diego, La Jolla, California
 R. Byers, University of Kansas, Lawrence, Kansas
 T. F. Coleman, Cornell University, Ithaca, New York
 J. W. Demmel, Courant Institute/New York University, New York, New York
 R. Entriken, Stanford University, Stanford, California
 R. H. W. Fermg, North Carolina State University, Raleigh, North Carolina
 W. B. Gragg, Naval Postgraduate School, Monterey, California
 C. P. Hansen, University of Tennessee, Knoxville, Tennessee
 G. Golub, Stanford University, Stanford, California
 S. Keller-McNulty, Kansas State University, Manhattan, Kansas
 D. Kinkaid, University of Texas-Austin, Austin, Texas
 V. Kema, Massachusetts Institute of Technology, Cambridge, Massachusetts
 V. Kresimir, Fernuniversitat Hagen, Dortmund, West Germany
 R. LeVeque, University of Tennessee, Knoxville, Tennessee
 J. Liu, York University, Ontario, Canada
 T. H. Olesen, Christian Mich., Bergen, Norway
 J. Ortega, University of Virginia, Charlottesville, Virginia
 H. Park, University of Minnesota, Minneapolis, Minnesota
 B. Parlett, University of California, Berkeley, California
 T. Peierls, Cornell University, Ithaca, New York
 R. J. Plemmons, North Carolina State University, Raleigh, North Carolina
 A. Pothen, Pennsylvania State University, University Park, Pennsylvania
 M. Saunders, Stanford University, Stanford, California
 W. D. Shoaff, Florida Institute of Technology, Melbourne, Florida
 D. Sorensen, Argonne National Laboratory, Argonne, Illinois
 G. W. Stewart, University of Maryland, College Park, Maryland
 G. O. Svensson, Linkoping University, Linkoping, Sweden
 K. Veselic, Fernuniversitat Hagen, Cortmund, West Germany
 B. R. Vona, University of Texas-Austin, Austin, Texas
 D. Warner, Clemson University, Clemson, South Carolina
 S-Y. Xiao, University of Tennessee, Knoxville, Tennessee
 D. Young, University of Texas-Austin, Austin, Texas

SCIENTIFIC AND PROFESSIONAL ACTIVITIES

October 1, 1987 — August 31, 1989

V. Alexiades

Invited papers

- "Shrinkage Effects on Solidification," 2nd International Conference on Trends in Welding Research, Gatlinburg, TN, May 1989.
- "Effect of a Void on Cyclic Melting and Freezing of an Encapsulated PCM," 26th National Heat Transfer Conference, Philadelphia, PA, August 1989.

Professor

- Mathematics Department, University of Tennessee, Knoxville, TN.

Award

- UTK-ORNL Science Alliance Research Incentive Award, 1986-1989.

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*
- NSF and DOE Proposals

F. S. Alsmiller

Member

- Superconducting Super Collider Task Force on Radiation Levels in the SSC Interaction Regions.

Invited paper

- "The Modified High-Energy Transport Code HETC and Design Calculations for the SSC," (with R. G. Alsmiller, Jr., T. A. Gabriel, O. W. Hermann, and B. L. Bishop) American Nuclear Society Meeting, San Diego, CA, June 12-16, 1988.

R. G. Alsmiller, Jr.

Chairman

- DOE Advisory Panel on Accelerator Radiation Safety for the Review of the Continuous Electron Beam Accelerator Facility (CEBAF).

Member

- National Committee of Radiological Protection Scientific Committee 52 on Conceptual Basis of the Calculation of Dose Distributions.
- Superconducting Super Collider Task Force on Radiation Levels in the SSC Interaction Regions.

Invited paper

- "The Modified High-Energy Transport Code HETC and Design Calculations for the SSC," (with F. S. Alsmiller, T. A. Gabriel, O. W. Hermann, and B. L. Bishop) American Nuclear Society Meeting, San Diego, CA, June 12-16, 1988.

Referee

- *Nuclear Science and Engineering*
- *Physics in Medicine and Biology*
- *Health Physics*
- *Fusion Nuclear Technology*

Y. Y. Aziny**Chairman**

- Neutron Transport and Thermalhydraulics Session, 1989 American Nuclear Society Annual Meeting, Atlanta, GA, June 1989.

Referee

- *Nuclear Science and Engineering*

J. J. Beauchamp**Invited paper**

- "Bayesian Variable Selection in Linear Regression," (with T. J. Mitchell) 1988 Joint Statistical Meetings, New Orleans, LA, August 22-25, 1988.

Invited lecture

- "Bayesian Variable Selection and Linear Regression," Department of Statistics, University of Tennessee, October 18, 1988.

Awards

- 1988/89 Technical Communication Award by the East Tennessee Chapter of the Society for Technical Communication.
- 1989 Martin Marietta Team Award for Publications (with T. J. Mitchell).

Instructor

- Oak Ridge Graduate School of Biomedical Sciences, University of Tennessee, Knoxville, TN.

Referee

- *Water Resources Bulletin*
- *Soil Science Society of America Journal*
- *Canadian Journal of Fisheries and Aquatic Sciences*

K. O. Bowman**Member**

- Committee of History of Statistics, video presentation of Sesquicentennial, American Statistical Association.
- Advisory Committee on Equal Opportunities in Science and Engineering, National Science Foundation.
- Advisory Board, *Journal of Statistical Computation and Simulation*.
- International Editorial Board, *Communications in Statistics*.
- Proposal Review Panel, National Science Foundation.
- Nominating Committee, Oak Ridge Chapter, Sigma Xi, 1983–1989.

Chair

- Subcommittee on Scientists and Engineers with Disabilities, Equal Opportunities in Science and Engineering, National Science Foundation.
- Coordinating Committee on Equal Opportunities in Statistics, American Statistical Association.

Invited papers

- "Solutions to Johnson's S_B and S_U ," (with L. R. Shenton) *Commun. Statist.-Simula. Computa.*, 17(2), 343–348.
- " S_B and S_U Distributions fitted by Percentiles: A General Criterion," (with L. R. Shenton) *Commun. Statist.-Simula. Computa.*, 18(1), 1–13.
- Commentary, "Eight Billion Mice is the Answer. What is the Question?" to appear in Citation Classics section of *Current Contents*, October 16, 1989.

Contributing editor

- *Current Index to Statistics*

Organizer

- Open Meeting, ASA Annual Meeting, New Orleans, August 1988.
- Open Meeting, ASA Annual Meeting, Washington, DC, August 1989.

Award

- Distinguished and Sustained Contributions to Science Award, AWIS, 1988.
- Technical Achievement Award, Martin Marietta Energy Systems, Inc., 1988.

Reviewer

- *Science, American Association for the Advancement of Science*
- Research Proposal, National Science Foundation.

Referee

- *Communications in Statistics*
- *Computational Statistics & Data Analysis*
- *American Statistician*
- *Journal of Statistical Computation and Simulation*
- *Psychometrika*

R. J. Carter**Invited papers**

- "Digital Instrumentation and Interactive Computer Systems: A Survey of the Use of Advanced Technology in the Nuclear Industry," American Institute of Chemical Engineers Summer National Meeting, Philadelphia, PA, August 21–23, 1989.
- "Human Factors Aspects of Advanced Instrumentation in the Nuclear Industry," Institute of Electrical and Electronics Engineers Symposium on Power Plant Dynamics, Control, and Testing, Knoxville, TN, May 15–17, 1989.
- "Review Criteria for Human Factors Aspects of Advanced Controls and Instrumentation," (with R. E. Uhrig), Nuclear Safety Research Review Committee's Subcommittee Meeting on Human Factors and Reliability, Brookhaven National Laboratory, December 1–2, 1988.
- "Designing a HAZMAT Incident Management System for Facilities with Widely Varying Emergency Organization Structures," (with C. E. Easterly), American Institute of Chemical Engineers Hazardous Material Spills Conference, Chicago, IL, May 16–19, 1988.

Session organizer

- Hands-On Demonstrations of Computer Models, ANS Topical Meeting on Advances in Human Factors Research on Man/Computer Interactions: Nuclear and Beyond.

J-C. Culioli**Award**

- Ph.D. Thesis was awarded the first prize in Theoretical Automatic Control by the AFCET, Paris, France (French Association for Cybernetics and Systems) (March 1988).

G. de Saussure**Member**

- Organizing Committee for the Topical Conference "Fifty Years with Nuclear Fission," National Bureau of Standards, Washington, DC, April, 26-28, 1989.
- International Program Committee International Topical Meeting on the Physics of Reactor Operation, Design, and Computation: Physor '90 (1990).

Assistant technical chairman

- ANS/ENSA 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 Society Standards Working Group 5.1, Decay Heat Standard.
- American Nuclear Society Standards Working Group 5.2, Fission Product Yields.
- Nuclear Energy Agency Task Force on Decay Heat Predictions.
- University Nuclear Engineering Research Program, Review Panel.
- Oak Ridge National Laboratory Speakers' Bureau.
- Oak Ridge Associated Universities DOE Traveling Lecture Program.
- Oak Ridge Associated Universities Tennessee Visiting Scientist Roster.

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

- "Review of New Integral Determinations of Decay Heat," Proceedings of a Specialists' Meeting on Data for Decay Heat Predictions, Studsvik, Sweden, September 7-10, 1987, NEACRP-302 'L,' NEANDC-245 'U' (OECD, Paris, 1987) p. 199.

Invited lectures

- "Decay Heat Measurements and the Loss of Coolant Accident," Nuclear Engineering Department, University of Tennessee, October 26, 1988.
- "Neutron Research at the Oak Ridge Electron Linear Accelerator," Physics Department, Ohio University, Athens, Ohio, April 7, 1989.
- "Reactor Safety and the Status of Commercial Nuclear Power in the U.S.," Public forum presentation, Ohio University, Athens, Ohio, April 7, 1989.

Referee

- *Nuclear Science and Engineering*
- *The Physical Review*
- *Nuclear Instruments and Methods*

F. C. Difilippo**Member**

- Program Committee Reactor Physics Division American Nuclear Society.

Invited lecture

- "Determination of Kinetics Parameters Using Stochastic Method in a ^{252}Cf Driven System," University of Michigan, October 1988.
- "Determination of Kinetics Parameters Using Stochastic Method in a ^{252}Cf Driven System," Institut of Nuclear Technology, Madrid, Spain, May 1988.

Invited papers

- "Reactor Physics Methods for the Preconceptual Core Design of the Advanced Neutron Source," American Nuclear Society 1988 Winter Meeting, November 26-30, 1989, San Francisco, CA.
- "Determination of Kinetics Parameters Using Stochastic Method in a ^{252}Cf Driven System," NATO Advanced Research Workshop, Valencia, Spain, May 1988.

Co-organizer

- Chairman, editor NATO Advanced Research Workshop on "Noise and Nonlinear Phenomena in Nuclear Systems," Valencia, Spain, May 1988. (Proceedings edited by Plenum, NATO ASI Series).
- ORNL Workshop on Scientific and Industrial Applications on Free Electron Laser, June 12-13, 1989.

Organizer

- Special Session of Winter 1988 American Nuclear Society Meeting about the Advanced Neutron Source.

Award

- Best paper award Reactor Physics Division. Winter 1988 ANS Meeting, co-author.

Fellow

- Elected Fellow American Nuclear Society, November 1988.

Listed

- International Directory of Nuclear Criticality Safety Personnel.

Referee

- *Nuclear Science and Engineering*

J. B. Drake**Member**

- Computing User Advisory Committee.
- Computing User Advisory Steering Committee.

Invited paper

- "Application of Parallel Computing to Scientific Problems," Tuskegee University, February 1989.

W. W. Engle, Jr.**Chairman**

- Membership Committee, Radiation Protection and Shielding Division, American Nuclear Society, through July 1988.

Award

- Elected American Nuclear Society Fellow.

Special assignment

- On assignment at the OECD-NEA Data Bank, Saclay, France, August 1988 through June 1990.

G. F. Flanagan**Member**

- American Nuclear Society Board of Directors 1987-1990.
- American Nuclear Society Finance Committee 1989-1992.
- American Nuclear Society Nuclear Reactor Safety Division Executive Committee.
- Society for Risk Analysis (Charter).

Board of directors

- American Nuclear Society (elected).

Treasurer

- Nuclear Reactor Safety Division – American Nuclear Society (elected).

Invited papers

- DOE-ER “HFIR PRA” Tutorial.
- DOE-ER “HFIR Safety and Operations” Tutorial.
- American Institute Chemical Engineer (AIChE) – Risks of Chemical Weapon Demilitarization.
- American Air Pollution and Waste Management – Risks Associated with Chemical Weapon Demilitarization.

Award

- Martin Marietta Energy System Technical Achievement Award.

Editorial board

- *Risk Analysis*

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.

Referee

- *The American Journal of Epidemiology*
- *Statistics in Medicine*
- *The American Statistician*
- *Radiation Research*

C. Y. Fu**Member**

- Cross Section Evaluation Working Group (CSEWG).
- NEANDC Activation Cross Section Working Group.

Invited papers

- "Status of Theories Used for Calculations of Long-Lived Activation Cross Sections," IAEA Consultants Meeting on the Generation of Long-Lived Radioactive Nuclides, Argonne, IL, September 11-12, 1989.

Referee

- *Nuclear Science and Engineering*

T. A. Gabriel**Spokesperson**

- ORNL High Energy Physics Task Force.

Member

- Task Force on Radiation Levels in the Experimental Halls at the SSC (DOE).
- Steering Committee of the Southern Association for High Energy Physics (SAHEP).

Publicity chairman

- Organizing Committee for the Southeastern Conference on the Superconducting Super Collider (SSC).

Invited papers

- "Calorimeter and Related Calculations for the SSC," the Second ORAU Workshop on the SSC, Atlanta, GA, May 12-13, 1988.
- "Detectors for the Superconducting Super Collider, Design Concepts, and Simulation," Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989.
- "Theoretical Studies of Hadronic Calorimetry for High Luminosity and High Energy Colliders," (with J. Brau) International Conference Advanced Technology and Particle Physics, Villa Olmo, Lake Como, Italy, June 15, 1988 (NIM, A279, 40-56 (1989)).
- "The Modified High-Energy Transport Code, HETC, and Design Calculations for the SSC," (with R. G. Alsmiller, Jr., F. S. Alsmiller, O. W. Hermann, and B. L. Bishop) 1988 Annual Meeting of the ANS, San Diego, CA, June 12-16, 1988.
- "CALOR89: The Code System for Calorimeter Analysis and Design," Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989.

- "Silicon Calorimetry, A Computational Perspective," Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989.
- "Methods Used in the MORSE Code for Computational Speedup," Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989.
- "The High-Energy Transport Code HETC88," (with R. G. Alsmiller, Jr., F. S. Alsmiller, O. W. Hermann, and J. M. Barnes) Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989.

Referee

- *Nuclear Science and Engineering*
- *Nuclear Instruments and Methods*
- *Nuclear Technology/Fusion*

C. W. Glover

Organizer

- Aerospace Applications of Artificial Intelligence (AAAIC) Robotics and Control Section Organizer.

Invited lectures

- "Neural Networks for Pattern Classification," ORNL Fusion Energy Division Seminar.
- "Neural Networks and Adaptive Resonance Theory (ART I)," Ohio Neural Networks Society.
- "Applications of Neural Networks at ORNL," Ohio Neural Networks Society; also University of Tennessee Nuclear Engineering Seminar.

L. J. Gray

Invited talk

- "Boundary Element Method for Regions with Cracks," SIAM Meeting, Knoxville, TN, March 17-18, 1989.

Invited paper

- "Evaluation of Hypersingular Integrals in the Boundary Element Method," *Computers and Mathematics with Applications*, accepted 1989.

Editorial board

- Engineering Analysis with Boundary Elements
- Electrosoft
- Boundary Elements: Abstracts and Newsletters

Referee

- *National Science Foundation*

C. M. Haaland**Advisor**

- National Council for Radiation Protection and Measurements Scientific Committee #63, Radiation Exposure Control in a Nuclear Emergency, Lewis V. Spencer, chairman.

Member

- Hypersonic Glide Vehicle Mission Analysis Working Group.

Invited paper

- "Fallout Facts for Nuclear-Battlefield Commanders," Armed Forces Radiobiology Research Institute, Bethesda, MD, September 9, 1988.

Referee

- *Journal of Civil Defense*
- *Journal of Health Physics*

J. A. Harvey**Member**

- ORNL Accelerators and Radiation Sources Review Committee.
- Panel on Basic Nuclear Data Compilations National Research Council.

Labor coordinator

- Engineering Physics and Mathematics Division.

Safety officer

- Engineering Physics and Mathematics Division.

Radiation control officer

- Engineering Physics and Mathematics Division.

Chairman

- Executive Committee, Electromagnetic Isotope Enrichment Facility Users Group, 1987.

Referee

- *Physical Review C* and *Physical Review Letters*
- *Nuclear Science and Engineering*

M. T. Heath**Member**

- Board of Directors, ACM-SIGNUM.
- Martin Marietta Technical Achievement Award Committee.

- Organizing Committee, Fifth Distributed Memory Computing Conference Series.
- Organizing Committee, Fourth Hypercube Concurrent Computers Conference.

Referee

- *SIAM Journal Scientific and Statistical Computing*
- *IMA J. Numer. Anal.*
- *Mathematical Programming*
- *Nuclear Science and Engineering*
- *IEEE Computer*
- *IEEE Trans. on Computers*
- *Concurrency: Practice and Experience*

Proposal reviewer

- National Science Foundation

Chairman

- Steering Committee, Distributed Memory Computing Conference Series

Vice-chairman

- ACM SIGNUM (Special Interest Group on Numerical Mathematics)
- SIAG-LA (SIAM Activity Group on Linear Algebra)

Invited lectures

- Workshop on Vector and Parallel Computing, Umea, Sweden, 1988.
- Danish Summer School in Supercomputing, Copenhagen, Denmark, 1989.

D. T. Ingersoll

Member

- Nuclear Energy Agency Committee on Reactor Physics (NEACRP)
- ORNL Research Reactors Users Group.
- ORNL Nuclear Energy Panel.

Vice-chair/chair-elect

- Radiation Protection and Shielding Division, American Nuclear Society.

Chairman

- Shielding Data Testing Subcommittee, Cross-Section Evaluation Working Group (CSEWG).
- U.S.-JASPER Shielding Program Working Group.

Reviewer

- DOE Nuclear Engineering Research Program.

B. L. Kirk**Membership chairman**

- American Nuclear Society, Radiation Protection and Shielding Division.

Member

- American Nuclear Society (ANS-10 Standards Committee).
- Society for Industrial and Applied Math Special Interest Group on Supercomputing.

H. E. Knee**Member**

- American Nuclear Society
- EPRI Chapter 10 Man/Machine Interface Requirements Committee.

Technical chairman

- ANS Topical Meeting on Advances in Human Factors Research on Man-Computer Interactions: Nuclear and Beyond.

D. C. Larson**Member**

- Department of Energy Nuclear Data Committee.
- NEANDC International Task Force on Evaluation Cooperation.
- Evaluation Methods Subcommittee, Cross Section Evaluation Working Group (CSEWG).
- Resonance Region Subcommittee, CSEWG.

Invited papers

- "ENDF/B-VI Nuclear Data Evaluations for Fusion Applications," (with C. Dunford and P. Young) Eighth Topical Meeting on Technology of Fusion Energy, Salt Lake City, UT, October 9-13, 1988.
- "Structural and Shielding Material Evaluations for ENDF/B-VI," (with P. Young) American Nuclear Society Winter Meeting, San Francisco, CA, November 26-30, 1989.
- "Electron Linear Accelerators for Fast Neutron Data Measurements in Support of Fusion Energy Applications," (with K. Bockhoff, A. Carlson, O. Wasson, and J. A. Harvey) for special issue of *Nuclear Science and Engineering on Neutron Sources for Fusion Technology*.

Chairman

- Working Group A, Office of Nuclear Physics Committee on Nuclear Data for Fusion Reactor Applications.
- Working Group 2, IAEA Specialist's Meetings on Fusion Evaluated Nuclear Data Library.
- Co-chairman of General Purpose Evaluations Subcommittee, CSEWG.

Proposal reviewer

- Office of Nuclear Physics, Department of Energy, Low Energy Nuclear Physics.

Referee

- *Nuclear Science and Engineering*

M. R. Leuze**Invited papers**

- "Independent Set Orderings for Parallel Matrix Factorization by Gaussian Elimination," *Parallel Computing* 10, 177-191 (1989).
- "Multiprogramming a Distributed-Memory Multiprocessor," (with L. W. Dowdy and K. Y. Park) *Concurrency: Practice and Experience* 1 (1989).

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**Fellow**

- American Association for the Advancement of Science.
- American Physical Society.

Referee

- *Nuclear Science and Engineering*
- *Physical Review*

R. E. Maerker**Member**

- ASTM E10.05 Subcommittee Member Ad-Hoc Committee to Prepare Guide on LWR-RPV' Surveillance Analysis for NRC.
- American Nuclear Society.
- American Society for Testing and Materials.

Invited paper

- "The LEPRICON Code System: Consolidation of Transport Analytical and Unfolding Procedures in LWR Pressure Vessel Dosimetry," *Trans. Am. Nucl. Soc.* 57, 225 (1988).

Referee

- *Nuclear Science and Engineering*
- *Journal of Nuclear Materials*, Amsterdam, Holland

R. C. Mann**Member**

- Advisory Committee for the Universidad del Turabo, Puerto Rico, Engineering Curriculum Development.

Invited papers

- "Sensor Integration Using Concurrent Computing On-Board the ORNL Mobile Robot," IEEE R&A Conference, Scottsdale, AZ.
- "Research in Mobile Robotics at ORNL/CESAR," IEEE International Conference Systems Engineering, Dayton, OH.
- "Multi-Sensor Integration for a Mobile Robot," International Workshop on Robot Hands, Dubrovnik, Yugoslavia.

Chairman

- Review Team for the Robotics Part of the DOE Environmental Restoration and Waste Management Program Plan.

Reviewer

- *IEEE Trans. Systems, Man, Cybernetics*
- *IEEE Computer*
- *IEEE J. Robotics & Automation*
- DOE SBIR Program

T. J. Mitchell**Invited papers**

- "A Bayesian Approach to the Design and Analysis of Computational Experiment," Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21–23, 1987.
- "A Bayesian Approach to the Design and Analysis of Computer Experiments," (with M. D. Morris) 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21–23, 1988.
- "A Bayesian Approach to the Design and Analysis of Computer Experiments," (with M. D. Morris) First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25–28, 1988.
- "Bayesian Variable Selection in Linear Regression," (JASA Theory and Methods Special Invited Paper) Joint Statistical Meetings, New Orleans, LA, August 22–25, 1988.
- "Computer Experiments to Optimize a Compression Mold Filling Process, Workshop on Design of Computer Experiments, Oak Ridge, TN, November 3–5, 1988.
- "Design and Analysis of Computer Experiments in Chemistry and Chemical Engineering," (with M. D. Morris) 1989 Gordon Research Conference on Statistics in Chemistry and Chemical Engineering, New Hampton, NH, July 31–August 4, 1989.

Invited talks

- "A Bayesian Approach to the Design and Analysis of Computational Experiments," (with M. D. Morris) Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21–23, 1987.
- "A Bayesian Approach to the Design and Analysis of Computer Experiments," (with M. D. Morris) 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21–23, 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with M. D. Morris) IBM Scientific Centre, Bergen, Norway, July 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with M. D. Morris) University of Augsburg, Augsburg, Germany, July 1988.
- "A Bayesian Approach to the Design and Analysis of Computational Experiments," (with M. D. Morris) First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25–28, 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with M. D. Morris) First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25–28, 1988.

- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with M. D. Morris) University of Reading, Reading, England, August 1988.
- "Design and Analysis of Computer Experiments in Chemistry and Chemical Engineering," (with M. D. Morris) 1989 Gordon Research Conference on Statistics in Chemistry and Chemical Engineering, New Hampton, NH, July 31–August 4, 1989.

Awards

- 1988 Martin Marietta Energy Systems Publication Award (2).
- 1988 Martin Marietta Energy Systems Author of the Year.

M. D. Morris

Member

- Editorial Board – *Journal of Quality Technology*

Invited papers

- "Two-Stage Factor Screening Procedures Using Multiple Grouping Assignments," *Commun. Statist.-Theor. Meth.* 16(10), 3051–3068 (1987).
- "A Bayesian Approach to the Design and Analysis of Computational Experiment," (with T. J. Mitchell) Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21–23, 1987.
- "A Bayesian Approach to the Design and Analysis of Computer Experiments," (with T. J. Mitchell) 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21–23, 1988, Eds. E. J. Wegman, D. T. Gantz, and J. J. Miller, pp. 49–51, American Statistical Association, 1988.
- "Book Review of 'Cyclic Designs' by J. A. John," *Technometrics* 30(120), 455–456 (1988).

Invited talks

- "A Bayesian Approach to the Design and Analysis of Computational Experiments," (with T. J. Mitchell) Thirty-Third Conference on the Design of Experiments in Army Research, Development and Testing, Newark, DE, October 21–23, 1987.
- "A Bayesian Approach to the Design and Analysis of Computer Experiments," (with T. J. Mitchell) 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21–23, 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with T. J. Mitchell) IBM Scientific Centre, Bergen, Norway, July 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with T. J. Mitchell) University of Augsburg, Augsburg, Germany, July 1988.

- "A Bayesian Approach to the Design and Analysis of Computational Experiments," (with T. J. Mitchell) First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25-28, 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with T. J. Mitchell) First International Conference-Workshop on Optimal Design and Analysis of Experiments, Neuchatel, Switzerland, July 25-28, 1988.
- "Computer Construction of Optimal Designs for Prediction in Computer Experiments," (with T. J. Mitchell) University of Reading, Reading, England, August 1988.
- "Bayesian Design and Analysis of Computer Experiments: Use of Derivatives in Surface Prediction," Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3-5, 1988.
- "The Role of Assumptions in Statistical Modeling," Health Physics Society Annual Meeting, Albuquerque, NM, June 28, 1989.
- "Factorial Sampling Plans for Preliminary Computational Experiments," 1989 Joint Statistical Meetings, Washington, DC, August 6-10, 1989.
- "Design and Analysis of Computer Experiments in Chemistry and Chemical Engineering," (with T. J. Mitchell) 1989 Gordon Research Conference on Statistics in Chemistry and Chemical Engineering, New Hampton, NH, July 31-August 4, 1989.

Reviewer

- *Technometrics*

D. L. Moses

Chairman

- Oak Ridge Research Reactor Subcommittee of the ORNL Reactor Operations Review Committee.

Recording secretary

- MHTGR Subgroup of the New Production Reactor Physics Technical Working Group (Interlaboratory).

Treasurer

- Oak Ridge/Knoxville Section of the American Nuclear Society.

Invited talk

- "A Revisit to the Passively Safe Reactors," Chattanooga Engineers Club, August 28, 1989.

E. Ng

Invited lectures

"Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems," Department of Computer Science, Vanderbilt University, Nashville, TN, October 1, 1987.

- "Direct Solution of Sparse Linear Systems on Multiprocessors," Minisymposium on Sparse Matrix Computation on Vector and Parallel Computers, SIAM 35th Anniversary Meeting, Denver, CO, October 12–15, 1987.
- "Direct Solution of Sparse Nonsymmetric Linear Systems," Gatlinburg International Conference on Numerical Linear Algebra, Fairfield Glade, TN, October 19–23, 1987.
- "Recent Developments in the Direct Solution of Sparse Nonsymmetric Linear Systems," Department of Computer Science, University of Tulsa, Tulsa, OK, November 23, 1987; also Department of Mathematics, Oklahoma State University, Stillwater, OK, November 24, 1987.
- "Some Ideas in the Solution of Sparse Linear Least Squares Problems," Departments of Computer Science and Mathematics, The University of Tennessee, Knoxville, TN, February 29, 1988.
- "On the Complexity of Some Sparse Matrix Factorizations," AMS Sectional Meeting, Knoxville, TN, March 25–26, 1988.
- "Some Ideas in the Solution of Sparse Linear Least Squares Problems," Systems Optimization Laboratory, University of Stanford, Stanford, CA, March 31, 1988.
- "On the Parallel Direct Solution of Sparse Linear Systems," Workshop on Methods and Algorithms for PDS's on Advanced Processors, Austin, TX, October 17–18, 1988.
- "A Comparison of Some Methods for Solving Sparse Nonsymmetric Linear Systems," SIAM Symposium on Sparse Matrices, Gleneden Beach, OR, May 22–24, 1989.
- "Sparse Partial Pivoting Using Static Storage Schemes," IMSL, Inc., Houston, TX, July 7, 1989.

Invited papers

- "Parallel Algorithms for Matrix Computations," (with A. Geist and M. Heath) pp. 233–251 in *The Characteristics of Parallel Algorithms*, Editors, R. Douglass, D. Gannon, and L. Jamieson, MIT Press, Cambridge (1987).
- "Experiments with Method of Lines Solvers on a Shared-Memory Parallel Computer," (with S. Thompson and P. G. Tuttle) pp. 161–166 in *Advances in Computer Methods for Partial Differential Equations - VI*, Editor, R. Vichnevetsky, IMACS (1987).
- "Sparse Cholesky Factorization on a Local-Memory Multiprocessor," (with A. George, M. Heath, and J. Liu) pp. 58–75 in *Parallel Processing and Medium-Scale Multiprocessors*, Editor, A. Wouk, SIAM (1989).
- "Solution of Sparse Positive Definite Systems on a Hypercube," (with A. George, M. Heath, and J. Liu) to appear in *Journal of Computation and Applied Mathematics* (1989); also ORNL/TM-10865.
- "Parallel Sparse Gaussian Elimination with Partial Pivoting," (with A. George) in *Proc. of the Workshop on Supercomputers and Large-Scale Optimization: Algorithms Software Applications*, University of Minnesota, May 16–18, 1988; to appear as a special volume of *Annals of Operations Research*, North-Holland; also ORNL/TM-10866.

- "Parallel Direct Solution of Sparse Linear Systems," in *Parallel Supercomputing: Methods, Algorithms, and Applications*, G. F. Carey, Ed., pp. 157-176 (1989).

G. Ostrouchov

Invited talks and lectures

- "Sparse Matrix Computations in Analysis of Variance," presented at the University of Tennessee, in conjunction with the Numerical Linear Algebra Year and the Department of Statistics, Knoxville, Tennessee, February 25, 1988.
- "Statistical Computing on a Hypercube," presented at Kansas State University, Manhattan, Kansas, April 5, 1988.
- "Sparse Matrix Computations in Analysis of Variance," presented at Kansas State University, Manhattan, Kansas, April 7, 1988.
- "Statistical Computing on a Hypercube: Iterative Proportional Fitting," 20th Symposium on the Interface of Computing Science and Statistics, Reston, VA, April 21-23, 1988.
- "Sparse Matrix Computations in Statistics," a lecture at A Short Course on Numerical Solution of Least Squares Problems, in conjunction with the Numerical Linear Algebra Year, Knoxville, TN, May 2-6, 1988.
- "Sparse Matrix Computations in Analysis of Variance," Third SIAM Conference on Applied Linear Algebra, Madison, WI, May 23-26, 1988.

Associate editor

- *Journal of Statistical Computation and Simulation*

Organizer and chair

- "Minisymposium on Matrix Computations in Statistics," Third SIAM Conference on Applied Linear Algebra, Madison, WI, May 23-26, 1988.

R. W. Peelle

Member

- Cross Section Evaluation Working Group (CSEWG) Executive Committee.
- 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.
- U.S. member to International Nuclear Data Committee.
- International Advisory Committee for 1991 Jülich Conference on Nuclear Data.

Invited paper

- "Neutron Standard Cross Sections," 1988 Mito Conference on Nuclear Data for Science & Technology, Mito, Japan, June 1988.

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.

Referee

- *Nuclear Science and Engineering*
- *Physical Review*
- *Nuclear Physics*

R. T. Primm, III**Member**

- Executive Committee Local Section, American Nuclear Society.
- Technical Program Committee, 1990 Annual Meeting of American Nuclear Society.
- Reactor Operation Review Committee - TSF.

V. A. Protopopescu**Member**

- Editorial Board of the Series *Advances in Mathematics for Applied Sciences*, World Scientific.

Invited lecture

- "Propagators for Nonlinear Systems: Theory and Applications," (with D. G. Cacuci) 3rd International Workshop on Mathematical Aspects of Fluid and Plasma Dynamics, Salice Terme, Italy, September 1988.

Invited papers

- "Combat Modeling with Partial Differential Equations," FY 1987 Annual Meeting of the Applied and Computational Mathematics Program, DARPA, Washington, DC, October 1987.

- "Global Existence Theory for Symmetric Discrete Velocity Models," International Workshop on Discrete Velocity Models, Lattice Gas Dynamics, and Foundations of Hydrodynamics, Torino, Italy, September 1988.
- "Combat Modeling with Partial Differential Equations, Workshop on Attrition Modeling in Large-Scale Simulations, Dallas, TX, February 1989.
- "An Example of Reaction-Diffusion Systems with Competitive Interactions," 11th International Conference on Transport Theory, Blacksburg, VA, May 1989.

Proposal referee

- Office for Basic Energy Science.
- Natural Sciences and Engineering Research Council of Canada.

Reviewer

- *Mathematical Reviews*

Referee

- *Journal of Statistical Physics*
- *International Journal for Intelligent Systems*
- *Transport Theory and Statistical Physics*
- *Nuclear Science and Engineering*
- *SIAM Journal of Applied Mathematics*
- *Computer*

W. A. Rhoades

Invited paper

- "S_n Transport Calculations on Vector and Parallel Processors," *Trans. Am. Nucl. Soc.* 55, 320-321, Los Angeles, CA, November 1987.

Referee

- *Nuclear Science and Engineering*

R. W. Roussin

Member

- Panel on Reference Nuclear Data, representative for American Nuclear Society, Radiation Protection and Shielding Division.
- ANS 6.1.2: Shielding Cross Sections Committee.
- Shielding Data Testing and Applications Subcommittee, Cross Section Evaluation Working Group (CSEWG).
- ORNL Federal Credit Union Supervisory Committee.

Chairman

- Methods and Formats Committee, Cross Section Evaluation Working Group (CSEWG).
- Photon Interaction Evaluation Subcommittee, CSEWG.
- Nominations Committee, American Nuclear Society Radiation Protection and Shielding Division.
- Division coordinator, United Way campaign.

Referee

- *Nuclear Science and Engineering*
- *Nuclear Technology/Fusion*
- *Trans. of Symposia on Space Nuclear Power Systems*

D. L. Selby**Member**

- American Nuclear Society.
- Spectrum-90 Organizing Committee.
- WATtec 1989 Presidents Program Committee.

Vice-chairman

- 1990 Summer Meeting of the American Nuclear Society.

Invited paper

- Test, Research, and Training Reactor Meeting, October 1987.

M. S. Smith**Executive committee**

- Oak Ridge/Knoxville Section of American Nuclear Society.

M. Terranova**Member**

- Human Factors Society, Computer Systems Group, Metropolitan Chapter & Tidewater Chapter.
- Association for Computing Machinery, Special Interest Group on Human Computer Interaction.
- American Psychological Society.
- IEEE Society for Systems, Man, and Cybernetics.
- IEEE Society for the Social Implications of Technology.

Theses

- "Dynamic Allocation of Responsibility Between Operators with Different Models of System Information Using Computer-Mediated

Communication," Doctoral Dissertation, Old Dominion University, 1988 (in press); also submitted to *Dissertations Abstracts International*.

Invited presentations

- "The Individual and Organizational Impacts of Computer Systems," presentation made for the Senior Executive Seminar: Information Resources Management in the Navy Reserves, August 18, 1989.
- "Cognitive Skills for Complex Tasks," presentation made for the Data Systems R&D Program Advisory Committee, June 6, 1989.
- "Innovations in Cognitive Task Analysis: Techniques for Operators of Airborne Weapons Systems," presentation made for the First Annual Airborne Weapons Training Technology Review, March 30, 1989.

D. K. Trubey

Session organizer

- Special Session on Radiation Protection Standards, ANS Winter Meeting, November 1989.

Theses

- "JANE, A New Information Retrieval System for the Radiation Shielding Information Center," University of Tennessee, August 1988.

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.

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

Invited papers

- "Some Results on the Best of Paired Comparison," (with R. C. Hanumara and E. P. Quinn) *Applied Mathematics and Computation* **29**, 247-268 (1988).

- "Is p a Prime Number? Some Probabilistic Tests for Primality," (with S. R. Jammalamadaka) *Mathematical Scientist* 14, 55-61 (1989).

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.
- East Tennessee Chapter of the American Statistical Association.

Council member

- East Tennessee Chapter of the Society for Risk Analysis.

Organizing committee

- Seminar/Workshop on Theory and Pragmatics of Data Quality Control, April 21-22, 1988, Oak Ridge, TN.
- Session on Consensus Methods at the 1989 Joint Statistical Meetings, March 19-22, 1989, Lexington, KY.

Committee member

- American Statistical Association Committee for Nuclear Regulatory Research.

R. C. Ward

Member

- SIAM Council.
- Organization Committee for Gatlinburg X Meeting.
- Advisory Committee, 1989 Sparse Matrix Symposium.
- ORNL Working Group on Computing.
- Computer Science Site-Review Team, NSF Science & Technology Centers.

Invited paper

- "Matrix Computations on Parallel Computers," American Mathematics Society, 94th Annual Meeting, Atlanta, GA, January 6-9, 1988.

Chairman

- SIAM Activity Group on Linear Algebra.

Co-chairman

- UTK/ORNL Special Year in Numerical Linear Algebra.

Organizer

- ORNL Workshop I on Parallel Computing.
- ORNL Workshop II on Parallel Computing.
- Minisymposium on Influence of Architecture Upon Linear Algebra Algorithms, SIAM Annual Meeting, San Diego, CA, July 17-21, 1989.

Proposal reviewer

- NSF and DOE.

Fellow

- American Association for Advancement of Science.

C. R. Weisbin**Member**

- DOE Representative to the Department of Defense, Joint Directors of Laboratories, Robotics Technology Panel.
- Program Committee, IEEE International Conference on Robotics and Automation, 1988-1989.
- U.S. Robotics Representative to International Program Committee for "Supercomputing in Nuclear Applications."
- Martin Marietta Corporate Headquarters Steering Committee on Artificial Intelligence.
- IEEE Control Society: Committee on Intelligent Controls.

Chairman

- 1988 Workshop on Man-Machine Symbiotic Systems: Program Chairman.
- 1989 Chairman: Symposium on Robotics for the 8th International Congress of Cybernetics and Systems.
- (Program) Second International Conference on Artificial Intelligence.

Director

- Robotics and Intelligent Systems Program (RISP).
- Section Head, Mathematical Modeling and Intelligent Control.
- Center for Engineering Systems Advanced Research (CESAR).

Associate editor

- *IEEE Expert Intelligent Systems and Their Application*

Technical editor

Transactions on Robotics and Automation

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

- *IEEE Transactions on Robotics and Automation*
- *Journal of Robotic Systems*
- *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: 6th Edition.*

L. W. Weston**Co-chairman**

- Evaluation Committee of CSEWG (Cross Section Evaluation Working Group).

Invited paper

- "New Cross Section Evaluations for Reactor Fuel Materials," American Nuclear Society 1989 Winter Meeting, San Francisco, CA, November 26-30, 1989.

T. Wright**Chairman**

- American Statistical Association Advisory Committee to the U.S. Bureau of the Census (1988).

Invited participant

- Workshop of Demography of Scientists and Engineers with Disabilities, organized by American Statistical Association, AAAS and NSF.
- Defense Personnel Planning Workshop, organized by Committee on National Statistics of the National Academy of Sciences.

Invited lectures

- "Near With Replacement Sampling Without Replacement Using Ranks," The Washington Statistical Society, Washington, DC, April 13, 1988.
- "Near With Replacement Sampling Without Replacement Using Ranks," Statistics Department, Ohio State University, Columbus, OH, May 17, 1988.
- "Randomization, Simple Random Sampling, and Pascal's Triangle," NSF Summer Research Program for College Students in Mathematical Sciences, Mathematics Department, University of Tennessee, Knoxville, TN, July 15, 1988.
- "Near With Replacement Sampling Without Replacement Using Ranks," Statistics Department, University of Tennessee, Knoxville, TN, January 31, 1989.
- "Some Basic Concepts in Probability Sampling from a Finite Universe," NSF Summer Research Program for College Students in Mathematical Sciences, Mathematics Department, University of Tennessee, Knoxville, TN, June 28, 1989.

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 and Mathematics) University of Tennessee, Knoxville, TN.

Reviewer

- *Mathematical Reviews*
- *National Science Foundation*

Honor

- Elected to Membership to the International Statistical Institute, 1989.

Referee

- *The American Journal of Mathematical and Management Sciences*
- *The American Statistician*
- *Communications in Statistics*
- *Metrika*

CONFERENCES

1987

"Short Course on Parallel Computing," September 28–October 2, 1987, Oak Ridge, Tennessee

Organizer: M. T. Heath
Attendees: 26
Sponsor: ORNL, Mathematical Sciences Section

"Workshop on the Solution of Sparse Systems of Equations," October 5–9, 1987, Knoxville, Tennessee

Organizers: R. C. Ward and J. A. George
Attendees: 40
Sponsors: ORNL, Mathematical Sciences Section, DOE Applied Mathematical Sciences Research Program, Science Alliance Program of the University of Tennessee, National Security Agency, National Science Foundation, U.S. Air Force Office of Scientific Research

"Gatlinburg X Conference on Numerical Algebra," October 18–23, 1987, Fairfield Glade, Tennessee

Co-Chairmen: R. C. Ward (ORNL) and G. W. Stewart (University of Maryland)
Attendees: 100
Sponsors: ORNL, Mathematical Sciences Section, DOE Applied Mathematical Sciences Research Program

1988

"Workshop on Eigenvalues and Singular Values," January 11–15, 1988, Knoxville, Tennessee

Organizers: R. C. Ward and J. A. George
Attendees: 45
Sponsors: ORNL, Mathematical Sciences Section, DOE Applied Mathematical Sciences Research Program, Science Alliance Program of the University of Tennessee, National Security Agency, National Science Foundation, U.S. Air Force Office of Scientific Research

" ^{235}U and ^{239}Pu Resonance Prescriptions," February 1988

Organizers: G. de Saussure and M. Moore (LANL)
 Attendees: 30
 Sponsor: ORNL, Nuclear Data Measurement and Evaluation Section

"Training Workshop for the PUFF/TFT Computer Codes," March 29–31, 1988, Oak Ridge, Tennessee

Organizer: M. S. Smith
 Attendees: 9
 Sponsor: ORNL

"Workshop on Matrix Least Squares Problems," April 4–8, 1988, Knoxville, Tennessee

Organizers: R. C. Ward and J. A. George
 Attendees: 35
 Sponsors: ORNL, Mathematical Sciences Section, DOE Applied Mathematical Sciences Research Program, Science Alliance Program of the University of Tennessee, National Security Agency, National Science Foundation, U.S. Air Force Office of Scientific Research

"Theory and Pragmatics of Data Quality Control Workshop," April 21–22, 1988, Oak Ridge, Tennessee

Organizers: V. R. R. Uppuluri, G. E. Liepens, and D. M. Flanagan
 Attendees: Expect ~70
 Sponsors: Data Systems Research and Development Program

"NATO Advanced Research Workshop on Noise and Nonlinear Phenomena in Nuclear Systems," May 23–27, 1988, Valencia, Spain

Organizers: J. L. Munoz-Cobo and F. C. Difilippo
 Attendees: 40
 Sponsors: NATO, Spanish Government, ORNL

"Design for Computer Experiments," November 2-5, 1988, Oak Ridge, Tennessee

Organizer: T. J. Mitchell

Attendees: 40

Sponsor: National Science Foundation, Air Force Office of Scientific Research, U.S. DOE Applied Mathematical Sciences Research Program and ORNL

"ENDF/B-VI Phase I Review Workshop," December 5-8, 1988, Oak Ridge, Tennessee

Organizer: D. C. Larson

Attendees: 30

Sponsor: ORNL, Nuclear Data Measurement and Evaluation Section

"DOE/NE Robotics for Advanced Reactors - First Concerted Robot Experiment," December 14, 1988, Oak Ridge National Laboratory, Oak Ridge, Tennessee

Organizer: R. C. Mann

Attendees: 35

Sponsor: ORNL

1989

"Organizing Workshop for the Southern Association for High Energy Physics," February 24, 1989, Oak Ridge, Tennessee

Organizers: Hugh Brashear, T. A. Gabriel, and J. Gunnick

Attendees: 60

Sponsors: ORAU and ORNL

"1989 CESAR/CEA Workshop on Autonomous Robots," May 30-June 1, 1989, Oak Ridge, Tennessee

Organizer: F. G. Pin

Attendees: 20

Sponsor: Center for Engineering Systems Advanced Research (CESAR)

"Robotics and Intelligent Interfaces Program, The Second International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems," June 6-9, 1989, Tullahoma, Tennessee

Organizer: F. G. Pin

Attendees: 320

Sponsors: The University of Tennessee Space Institute, Association for Computing Machinery - Sigart, Cooperating Organizations: American Association for Artificial Intelligence, IEEE - Computer Society, Oak Ridge National Laboratory, Oak Ridge Associated Universities, UTRC - Hertel Events, National Society of Professional Engineers.

"Workshop on the FITCAL Calorimeter for the SSC," April 18, June 1, July 14, August 31, September 22, 1989

Organizers: Hugh Brashear, T. A. Gabriel, and J. Walker

Attendees: 15

Sponsors: ORNL and University of Florida

"Workshop on Scientific and Industrial Applications of Free Electron Laser," June 12-13, 1989, Oak Ridge National Laboratory, Oak Ridge, Tennessee

Organizers: F. C. Difilippo and R. B. Perez

Attendees: 30

Sponsor: ORNL

"Workshop on a Hybrid Central Tracking Detector for the SSC," July 25, August 2, August 17, 1989

Organizers: Hugh Brashear, T. A. Gabriel, and A. L. Goshaw

Attendees: 20

Sponsors: Duke University and ORNL

"Workshop on the FAST Detector for the SSC," September 7-8, 1989, Oak Ridge, Tennessee

Organizers: Hugh Brashear, T. A. Gabriel, and Larry Price

Attendees: 60

Sponsors: ANL and ORNL

"Workshop on a Silicon Calorimeter for the SSC," September 11, 1989

Organizers: Hugh Brashear, W. Bugg, and T. A. Gabriel

Attendees: 15

Sponsor: ORNL and University of Tennessee

"Workshop on CALOR89," September 20-21, 1989, Oak Ridge, Tennessee

Organizer: T. A. Gabriel

Attendees: ~35

Sponsor: ORNL

SEMINARS AT ORNL

M. Beckerman was seminar coordinator during the period covered by this report. The following seminars were held during October 1987 through August 1989.

- V. Alexiades, Engineering Physics and Mathematics Division, "Nonsymmetric, Strongly Coupled, Quasilinear, Parabolic Systems"
- B. J. Allen, Lucas Heights Research Laboratory, Australia, "Neutron Diagnosis and Therapy: A Physicist's Incursion into Medicine"
- R. G. Alsmiller, Jr., C. West, R. T. Primm, III, and F. C. Difilippo, Engineering Physics and Mathematics Division, "The Advanced Neutron Source"
- J. L. Barlow, Computer Science Department, The Pennsylvania State University, University Park, PA, "Algorithms for Equality-Constrained Least-Squares Problems"
- K. Barry, Brigham Young University, Provo, UT, "Graphical Representation of Sparse Matrix Elimination Trees on a Sun Workstation"
- A. Björck, Department of Mathematics, Linköping University, Linköping, Sweden, "Stability Analysis of the Method of Seminormal Equations for Linear Least-Squares Problems"
- V. Boffi, University of Bologna, Italy, "Dynamical Systems from Nonlinear Particle Transport"
- D. Boley, Computer Science Department, University of Minnesota, Minneapolis, MN, "The Nonsymmetric Eigenproblem—A Prototype Hypercube Implementation"
- J. Borenstein, Department of Mechanical Engineering, The University of Michigan, Ann Arbor, MI, "The Vector Field Histogram — Fast Obstacle Avoidance for Mobile Robots"
- B. Bradley, University of Virginia, Charlottesville, VA, "A Survey of Methods in the Optimal Control of the Stefan Problem"
- C. A. Brau, Physics Department, Vanderbilt University, Nashville, TN, "Free-Electron Laser Technology"
- R. Byers, Department of Mathematics, University of Kansas, Lawrence, KS, "A Toolbox for Very Special Eigenvalue Problems"
- D. Cain, State University of New York at Oswego, "A Graphics Package for Displaying Sparse Matrices on a Sun Workstation"
- I. Cavers, Department of Computer Science University of British Columbia, "Using Deficiency Measure for Tiebreaking the Minimum Degree Algorithm"

- M. R. Celis, IMSL, Inc., Houston TX, "A Trust-Region Strategy for Nonlinear Equality Constrained Optimization"
- W. Celmaster, D. Fanton, and Richard Schaff, BBN Advanced Computers, Inc., "The Butterfly GP1000 Parallel Processor"
- B. W. Char, Department of Computer Science, The University of Tennessee, Knoxville, TN, "Automatic Old-Fashioned Analysis of Numerical Stability"
- H. I. Christensen, Laboratory of Image Analysis, Aalborg University, Denmark, "Monitoring Railway Crossings in Real Time: An Application in Computer Vision"
- A. Cleary, University of Virginia, Charlottesville, VI, "The Solution of Narrowly Banded Linear Systems on Parallel Computers by Direct Methods"
- T. Coleman, Department of Computer Science, Cornell University, Ithaca, NY, "Parallel Algorithms for Solving Systems of Nonlinear Equations on a Hypercube Computer"
- T. Coleman, Department of Computer Science, Cornell University, Ithaca, NY, "On the Convergence Analysis of Algorithms for Constrained Optimization"
- T. Coleman, Department of Computer Science, Cornell University, Ithaca, NY, "Exploiting Sparsity in Large-Scale Optimization"
- J.-C. Culioli, Engineering Physics and Mathematics Division, "Sigmoid Functions: A Delicate Tool to Design Some Optimization Algorithms"
- C. Currin, Bryn Mawr College, Bryn Mawr, PA, "Design and Analysis of Computational Experiments"
- H. Davis, Stanford University, Stanford, CA, "Characterizing the Synchronization Behavior of Parallel Programs"
- Eduardo D'Azevedo, Department of Computer Science, University of Waterloo, Ontario, "On Optimal Triangulation for Piecewise Linear Approximation"
- F. C. Difilippo and R. T. Primm, Engineering Physics and Mathematics Division, and C. D. West, Engineering Technology Division, "The Advanced Neutron Source (ANS)"
- D. L. Donohue and L. D. Hulett, Jr., Analytical Chemistry Division, "Experimental Applications of the Positron Facility at ORELA"
- L. Dowdy, Department of Computer Science, Vanderbilt University, Nashville, TN, "On the Partitioning of Multiprocessor Systems"
- D. Downing, Engineering Physics and Mathematics Division, and S. Bartell, Environmental Sciences Division, "Sensitivity and Uncertainty Analysis in Environmental Models"
- J. V. Draper, Fuel Recycle Division, "Teleoperator Human-Machine Interface Research at the Remote Systems Development Section"
- N. R. Draper, University of Wisconsin, Madison, WI, "Simple and Intricate Two-Level Designs"

- R. E. England, Department of Computer Science, The University of Tennessee, "Cliques and Their Separators in Triangulated Graphs"
- R. Entriken, Department of Operations Research, Student — Stanford University, Stanford, CA, "The Parallel Solution of the Stochastic Capacity Expansion Problem"
- L. Etheridge, Roanoke College, Salem, VA, "Graphical Animation of Message-Passing Parallel Algorithms"
- R. E. Flanery, Jr., Engineering Physics and Mathematics Division, "Multitasking and Multiprocessing on the CRAY-2"
- R. N. Fleischman, Independent Consultant, "Development and Verification of a Model of the Cognitive Contents of Displays"
- P. Fua, SRI International, Menlo Park, CA, "Objective Functions for Model-Based Vision"
- K. Gates, Applied Mathematics Department, University of Washington, Seattle, WA, "A Fast Variation of Cuppen's Method which Computes only the Eigenvalues of a Symmetric Matrix"
- G. A. Geist, Engineering Physics and Mathematics Division, "Finding Eigenvalues and Eigenvectors of Unsymmetric Matrices Using a Distributed-Memory Multiprocessor"
- G. A. Geist and E. Ng, Engineering Physics and Mathematics Division, "A Partitioning Strategy for Sparse-Matrix Factorization on Multiprocessors"
- J. A. George, UT/ORNL Distinguished Scientist, "On the Complexity of Sparse LU and QR Factorization of Finite-Element Matrices"
- M. E. Glicksman, Rensselaer Polytechnic Institute, Troy, NY, "Kinetics of Dendritic Growth"
- G. Golub, Computer Science Department, Stanford University, Stanford, CA, "The Theory of Moments in Linear Algebra"
- S. W. Hammond, Computer Science Department, Rensselaer Polytechnic Institute, "Architecture and Operation of a Systolic Engine for Finite Element Computations"
- C. Hansen, INRIA, Paris, France, "CAD-Based 3-Dimensional Computer Vision: The Automatic Generation of Recognition Strategies"
- P. C. Hansen, Copenhagen University Observatory, Kobenhavn K, Denmark, "Truncated CVD Solutions to Ill-Posed Problems With Ill-Determined Numerical Rank"
- C. T. Harston, Department of Computer Science, The University of Tennessee, Chattanooga, TN, "Neural Networks Used in Robotics Control"
- J. B. Hayter, Solid State Division, "Transport and Application of Cold Neutrons from ANSR"

- M. T. Heath, Engineering Physics and Mathematics Division, "Parallel Matrix Computations on Hypercubes"
- R. L. Iman, Sandia National Laboratory, Albuquerque, NM, "Bayesian Models for Time To Recovery and Initiating Event Frequency for Loss of Off-Site Power Incidents at Nuclear Power Plants"
- A. R. Ingraffea, Department of Civil and Environmental Engineering, Cornell University, Ithaca, NY, "Interactive Computer Simulation of Fracture Processes"
- E. Jessup, Department of Computer Science, Yale University, "Parallel Solution of the Symmetric Tridiagonal Eigenproblem"
- L. Kellerher, Ohio Northern University, Ada, OH, "A Graphical Interface for a Log-Linear Model"
- S. Keller-McNulty, Department of Statistics, Kansas State University, Manhattan, KS, "Error-Free Sparse Least Squares"
- T. Kerlin, Department of Nuclear Engineering, The University of Tennessee, Knoxville, TN, "Nuclear Engineering at The University of Tennessee"
- A. I. Khuri and G. G. Vining, Department of Statistics, University of Florida, Gainesville, FL, "Some Recent Developments in Response Surface Methodology"
- D. R. Kincaid, University of Texas at Austin, "Software and Numerical Experiments for Nonsymmetric Preconditioned Conjugate Gradient Methods"
- V. Klema, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, MA, "Robust Statistics Computations on Parallel Computing Machines"
- K. Knight, Meredith College, Raleigh, NC, "Use of Meet-in-the Middle Problem in Cryptanalysis of Closed Cryptosystems"
- S. Kundu, Louisiana State University, Computer Science Department, "Rule Discovery from Examples"
- E. Lazaridis, University of Pennsylvania, Philadelphia, PA, "The Use of Derivative Information in the Analysis of Multidimensional Computation Experiments"
- M. R. Leuze, Vanderbilt University, Nashville, TN, "Independent Set Orderings for Parallel Matrix Factorization by Gaussian Elimination"
- R. Leveque, Departments of Mathematics and Applied Mathematics, University of Washington, Seattle, WA, "Cartesian Grid Methods for Compressible Flow in Irregular Regions"
- K. Lindenberg, Department of Chemistry and Institute for Nonlinear Science, University of California, San Diego, CA, "Effects of Colored Noise on Linear and Nonlinear Dynamical Systems"

- K. Lindenberg, Department of Chemistry and Institute for Nonlinear Science, University of California, San Diego, CA, "How Does Energy Migrate in Molecular Aggregates?"
- J. W. H. Liu, Department of Computer Science, York University, Ontario, "Some Practical Aspects of Elimination Trees in Sparse Factorization"
- I. Lough, Rhode Island College, Providence, RI, "Generation of Tracefiles for Distributed-Memory Machines"
- V. Lumelsky, Department of Electrical Engineering, Yale University, New Haven, CT, "Robot Motion Planning Amidst Unknown Obstacles"
- B. J. MacLennan, Computer Science Department, The University of Tennessee, "Field Computation: A Basis for Neural, Optical and Molecular Information Processing"
- J. M. J. Madey, Department of Physics, Duke University, Durham, NC, "Infrared Free-Electron Laser Light Sources for University and Laboratory Research"
- L. K. Mansur, Metals and Ceramics Division, "On a Possible Mechanism for Accelerated Embrittlement in Pressure Vessel Steels"
- M. Marx, Physics Department, SUNY, Stonybrook, NY and SSC/CDG, Lawrence Berkeley Laboratory, CA "Alternative Approach to Superconducting Supercollider (SSC) Detectors"
- T. Miki, Power Reactor and Nuclear Fuel Development Corporation, Japan, "Japanese Artificial Intelligence Technology and Research"
- T. J. Mitchell, Engineering Physics and Mathematics Division, "Computer Construction of Optimal Designs for Prediction in Computer Experiments"
- T. J. Mitchell, Engineering Physics and Mathematics Division, "Computer Experiments to Optimize a Compression Mold Filling Process"
- T. J. Mitchell and J. J. Beauchamp, Engineering Physics and Mathematics Division, "Bayesian Variable Selection in Regression"
- T. J. Mitchell and M. D. Morris, Engineering Physics and Mathematics Division, "A Bayesian Approach to the Design and Analysis of Computational Experiments"
- D. A. Mitta, Human Factors Laboratory, Virginia Polytechnic Institute & State University, Blacksburg, VA, "Expert System Usability"
- R. Monaco, Politecnico di Torino, Torino, Italy, "Discrete Models in Kinetic Theory of Gases Analysis and Applications"
- M. D. Morris, Engineering Physics and Mathematics Division, "Bayesian Design and Analysis of Computer Experiments: Use of Derivatives in Surface Prediction"
- M. D. Morris, Engineering Physics and Mathematics Division, "A Bayesian Approach to the Design and Analysis of Computational Experiments"

- D. Mutchler, Computer Science Department, The University of Tennessee, Knoxville, TN, "Distributed Algorithms for Maintaining the Consistency of a Replicated File in the Face of Network Partitioning"
- M. Mutrie, University of Waterloo, "Towards a Symbolic System for Floating-Point Error Analysis"
- H. Nagao, College of Engineering, University of Osaka Prefecture, Japan, "On the Jackknife Statistics for Canonical Correlation Coefficients"
- E. Ng, Engineering Physics and Mathematics Division, "Some Ideas in the Solution of Sparse Linear Least-Squares Problems"
- E. Ng, Engineering Physics and Mathematics Division, "Direct Solution of Sparse Linear Systems on Multiprocessors"
- T. H. Olesen, Christian Michelsen Institute, Bergen, Norway, "Vectorized Dissection on the Hypercube"
- G. Ostrouchov, Engineering Physics and Mathematics Division, "Iterative Proportional Fitting of Log-Linear Models on a Hypercube"
- G. Ostrouchov, Engineering Physics and Mathematics Division, "Sparse-Matrix Computations in Analysis of Variance"
- H. Park, Department of Computer Science, University of Minnesota, Minneapolis, MN, "Jacobi Algorithms for Eigenproblems on a Hypercube"
- T. Peierls, Department of Computer Science, Cornell University, "Sparse Gaussian Elimination in Essential Time"
- F. G. Perey, Engineering Physics and Mathematics Division, "Measured and Calculated Capture Detector Response Functions"
- I. Petr, University of California, Berkeley, and Technical University of Prague, Czechoslovakia, "Computer Modeling of International Relations: Alternative Defense Systems and Prospects for Winding Down"
- B. W. Peyton, Boeing Computer Services, Seattle, WA, "A Fast Implementation of the Jess and Kees Algorithm Based on Clique Trees"
- R. J. Plemmons, Departments of Computer Science and Mathematics, North Carolina State University, Raleigh, NC, "Parallel Least Squares Algorithms in Signal Processing"
- D. A. Poplawski, Department of Computer Science, Michigan Technological University, Houghton, MI, "Two Aspects of Parallel Program/Architecture Characterization"
- R. Powell, Allegheny College, Meadville, PA, "A Debugging Interface for a Heterogeneous Network"
- L. Renker, DOE Science and Engineering Research Participant, "Survey of the Literature on Fractals with Possible Applications to Phase Change Processes"

- J. Roning, Oulu University, Oulu, Finland, "Model-Based Visual Navigation System for a Mobile Robot"
- P. Rusu, University of Colorado, Boulder, CO, "On the Wave-Particle-Like Solutions of Nonlinear Equations"
- B. N. Sanders, RichardsonSmith, Inc., Worthington, OH, "An 'Experiment' in Interdisciplinary Design"
- M. Saunders, Department of Operations Research, Stanford University, Stanford, CA, "Maintaining the Rank of Sparse LU Factors"
- A. D. Solomon, ORNL Consultant, Omer, Israel, "Simulation of a PCM-Impregnated Sensible Heat Wall"
- A. D. Solomon, ORNL Consultant, Omer, Israel, "The Simulation of a Thermal Performance of a Structure Containing Distribute Phase Change Material"
- V. S. Sunderam, Department of Mathematics and Comp/Science, Emory University, Atlanta, GA, "PVM: A Framework for Parallel Distributed Computing"
- S. Thompson, Mathematics and Statistics Department, Radford University, VA, "A New Approach for Handling Discontinuities Arising in the Solution of Differential Equations with State-Dependent Delays"
- S. Ting, Massachusetts Institute of Technology, "In Search of the Basic Building Blocks of Nature"
- R. I. Van Hook, Environmental Sciences Division, "Global Environmental Studies"
- C. Vaughan, University of Virginia, "The SSOR Preconditioned Conjugate Gradient Method on Parallel Computers"
- K. Veselić, Fernuniversität, Hagen, Germany, "On an Eigenreduction Algorithm for Definite Matrix Pairs"
- E. Wachspress, Department of Mathematics, The University of Tennessee, Knoxville, TN, "Iterative Solution of Sylvester's Equation"
- E. Wachspress, Department of Mathematics, The University of Tennessee, Knoxville, TN, "Essential Sparse LU Factorization"
- C. G. Wagner, The University of Tennessee, Knoxville, TN, "Consensus for Belief Functions and Related Uncertainty Measures"
- N. J. Wahls, Vanderbilt University, Department of Computer Science, Nashville, TN, "A Conceptual Framework for Distributed Debugging"
- R. M. Waldman, Atomic Energy Commission of Argentina, Buenos Aires, "Safety Analysis of MTR Cores"
- H. Watanabe, Department of Computer Science, University of North Carolina, Chapel Hill, NC, "VLSI Fuzzy Logic Inference Processor for Real-Time Control"

- S. M. Watt, IBM T. J. Watson Research Center, Yorktown Heights, NY, "The Scratchpad System for Algorithmic Mathematics"
- D. G. Wilson, Engineering Physics and Mathematics Division, "An Implicit, Finite Difference, Enthalpy Scheme and its Application to a Multidimensional Cyclic Melting and Freezing Problem"
- D. G. Wilson, Engineering Physics and Mathematics Division, "Changing Domains and Solidification Problems with Voids"
- P. H. Worley, Engineering Physics and Mathematics Division, "Limits on Parallelism in the Numerical Approximation of Linear PDEs"
- T. Wright, Engineering Physics and Mathematics Division, "Near Probability Proportional to Size (π ps) Sampling with Replacement Which is Without Replacement Based on Ranks"

PUBLICATIONS

ALEXIADES, V.

"Effect of a Void on Cyclic Melting and Freezing of an Encapsulated PCM," book chapter in *Multiphase Flow Heat and Mass Transfer*, ASME HTD, Vol. 109, pp. 17-20, R. K. Shak, Ed., American Society of Mechanical Engineers, New York, 1989. (1.54)[†]

"Void Formation in Solidification," book chapter in *Differential Equations*, Vol. 118, pp. 17-23, C. M. Dafermas, G. Ladas, and G. Papaiochou, Eds., Lecture Notes in Pure and Applied Math., Marcel Dekker, New York, 1989. (1987)

ALEXIADES, V., AND A. D. SOLOMON

"The Formation of a Solid Nucleus in Supercooled Liquid, Part II," *J. of Non-Equilibr. Thermodyn.* 14, 99-109 (1989). (1987)

ALEXIADES, V., A. D. SOLOMON, AND D. G. WILSON

"The Formation of a Solid Nucleus in Supercooled Liquid, Part I," *J. of Non-Equilibr. Thermodyn.* 13, 281-300 (1988). (1987)

ALEXIADES, V., AND R. WICHNER*

"Calculation of the Specific and Volumetric Enthalpies of Ge-Si Alloys," ORNL/TM-10548 (April 1988).

ALSMILLER, F. S., AND R. G. ALSMILLER, JR.

"Inclusion of Correlations in the Empirical Selection of Intracascade Nucleons from High-Energy Hadron-Nucleus Collisions," ORNL/TM-11032 (January 1989); also *Nucl. Instrum. Methods Phys. Res. A278*, 713-721 (1989). (4.35)

ALSMILLER, R. G., JR., F. S. ALSMILLER, AND O. W. HERMANN*

"Calculated Inclusive Neutron Production from 400 GeV Proton-Nucleus Collisions," ORNL/TM-11257 (August 1989). (4.38)

AZMY, Y. Y.

"The Weighted Diamond Difference Form of Nodal Transport Methods," *Nucl. Sci. Eng.* 98, 29 (1988). (1987)

[†] In 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. If neither an abstract number nor a year appears, then an abstract was not available for this report.

* Not a member of Engineering Physics and Mathematics Division.

"Comparison of Three Approximations to the Linear-Linear Nodal Transport Method in Weighted Diamond-Difference Form," *Nucl. Sci. Eng.* 100, 190 (1988). (1987)

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KOGER, K. H., J. HAIRE,* B. L. HUMPHRYS, J. F. MANNESCHMIDT,* K. SETOGUCHI,* AND R. NAKAI,* "Assessment of Critical Component Unavailability in Liquid Metal Reactors," p. 388. (3.132)

LEAL, L. C.,* G. DE SAUSSURE, AND R. B. PEREZ, "R-Matrix Analysis of the ^{235}U Neutron Cross Sections," p. 587. (2.40)

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LARSON, N. M.,* AND F. G. PEREY, "Resonance Parameter Analysis with SAMMY," pp. 573-576. (2.37)

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WRIGHT, T., "Randomization, Simple Random Sampling, and Pascal's Triangle." (1.91)

Oral Presentation, IBM Scientific Centre, Bergen, Norway, July 18, 1988

MITCHELL, T. J., AND M. D. MORRIS, "Computer Construction of Optimal Designs for Prediction in Computer Experiments." (1.91)

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HEATH, M. T., "Hypercube Applications at Oak Ridge National Laboratory." (1.9)

Oral Presentation, University of Augsburg, Augsburg, Germany, July 22, 1988

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PEREY, F. G., "Covariances of Physical Constants." (2.64)

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DIVADEENAM, M.,* T. A. GABRIEL, O. LAZERETH,* M. S. SPERGEL,* AND T. E. WARD,* "The Calculation of Cosmogenic Nuclide Abundance in Stony Meteorites." (4.41)

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BURKS, B. L., AND P. F. SPELT, "Ongoing Research Using HERMIES — The Hostile Environment Robotic Machine Intelligence Experiment Series." (3.11)

Tenth Annual DOE Low-Level Radioactive Waste Management Conference, Denver, CO, August 30-September 1, 1988; Proc. Session II: Site Performance Assessment (December 1988)

WORLEY, B. A., F. G. PIN, E. M. OBLOW, R. E. MAERKER, J. E. HORWEDEL,* AND R. Q. WRIGHT,* "Deterministic Sensitivity and Uncertainty Analysis for Large-Scale Computer Models," p. 126. (3.90)

10th Boundary Element Meeting, Southampton, United Kingdom, September 6-8, 1988; Proc. Boundary Elements X, Computational Mechanics, Southampton, England (1988)

GRAY, L. J., AND G. E. GILES,* "Application of the Thin Cavity Method to Shield Calculations in Electroplating." (1.81)

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CARTER, R. J., AND B. KARNOFSKY,* "A Generic Hazardous Waste Management Training Program." (3.131)

ORAU Visiting Lecture Series, North Carolina State University, Raleigh/Durham, NC, September 12, 1988

ROMINE, C. H., "The Evolution of Multiprocessing." (1.17)

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CHILDS, R. L.,* W. A. RHOADES, AND L. R. WILLIAMS, "Three-Dimensional Calculations of Neutron Streaming in the Beam Tubes of the ORNL HFIR Reactor," Vol. II, pp. 409-418. (4.9)

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Specialists' Meeting on the Application of Critical Experiments and Operating Data to Core Design via Formal Methods of Cross Section Data Adjustment, Jackson Hole, WY, September 23-24, 1988; Proc. NEACRP-L-307 (1988)

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WORLEY, P. H., "Limits on Parallelism in the Numerical Approximation of Linear PDEs." (1.52)

Third International Workshop on Mathematical Aspects of Fluid and Plasma Dynamics, Salice Terme, Italy, September 26-30, 1988

CACUCI, D. G.,* AND V. PROTOPODESCU, "Canonical Propagators for Nonlinear Systems: Theory and Sample Applications." (4.71)

Oral Presentation, University of Maryland, College Park, MD, September 29-30, 1988

HEATH, M. T., "Parallel Solution of Sparse Linear Systems." (1.39)

International Collaboration on Advanced Neutron Sources (ICANS-IX) Conference, Los Alamos, NM, October 3-7, 1988

LILLIE, R. A., AND R. G. ALSMILLER, JR., "Design Calculations for the ANS Cold Source." (4.25)

American Nuclear Society Eighth Topical Meeting on Technology of Fusion Energy, Salt Lake City, UT, October 9-13, 1988; Proc. Fusion Tech. 15(2) (March 1989)

DUNFORD, C. L.,* D. C. LARSON, AND P. G. YOUNG,* "ENDF/B-VI Nuclear Data Evaluations for Fusion Applications," p. 429-439. (2.70)

HETRICK, D. M.,* C. Y. FU, AND D. C. LARSON, "ENDF/B-VI Evaluations for Isotopes of Cr, Fe, Ni, and Cu, and for Natural Pb," p. 453. (2.52)

3rd International Seminar on Free Boundary Problems and Their Applications, Universidad Nacional de Rosario, Rosario, Argentina, October 11-15, 1988

WILSON, D. G., "Cyclic Melting and Freezing with Variable Density." (1.65)

WILSON, D. G., "Implicit Finite Difference Schemes for Phase Change Problems." (1.64)

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GABRIEL, T. A., M. DIVADEENAM,* M. S. SPERGER,* T. E. WARD,* AND O. LAZARETH, "Transport Calculation of Cosmogenic Nuclide Production in Stony Meteorites." (4.49)

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WORLEY, P. H., "Limits on Parallelism in the Numerical Approximation of Linear PDEs." (1.52)

Oral Presentation, Department of Statistics, University of Tennessee, Knoxville, TN, October 18, 1988

MITCHELL, T. J., AND J. J. BEAUCHAMP, "Bayesian Variable Selection in Linear Regression." (1.109)

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WILSON, D. G., J. B. DRAKE, AND R. E. FLANERY, "An Implicit, Finite Difference Enthalpy Scheme Applied to a Multidimensional Cyclic Melting and Freezing Problem with Variable Density." (1.68)

Human Factors Society 32nd Annual Meeting, Anaheim, CA, October 24-28, 1988; Proc. Vols. 1 and 2 (1988)

SEAMSTER, T. L.,* C. E. SNYDER,* M. TERRANOVA, W. J. WALKER,* AND D. T. JONES,* "Human Factors in the Naval Air Systems Command: Computer Based Training," Vol. 2, pp. 1095-1099. (3.115)

Oral Presentation, Applications Group Meeting, University of Illinois at Urbana-Champaign, Urbana, IL, October 25, 1988

HEATH, M. T., "Parallel Solution of Sparse Linear Systems." (1.39)

Oral Presentation, Department of Nuclear Engineering, University of Tennessee, Knoxville, TN, October 26, 1988

DICKENS, J. K., "Decay Heat Measurements and the Loss-of-Coolant Accident." (2.67)

American Mathematical Society Meeting, Lawrence, KS, October 29, 1988

GEIST, G. A., "The Unsymmetric Eigenvalue: Can HQR Be Beat?" (1.22)

1988 Winter Meeting of the American Nuclear Society, Washington, DC, October 30-November 3, 1988; Trans. Am. Nucl. Soc. 57 (1988)

AZMY, Y. Y., "Accuracy of Transport Calculations for the Advanced Neutron Source," p. 293. (4.6)

AZMY, Y. Y., "Artificial Intelligence Search Techniques for Optimization of the Cold Source Geometry," p. 97. (4.1)

CRAMER, S. N., "Analytic Solution of a Five-Direction Radiation Transport Model," p. 232. (5.2)

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GAMBILL, W. R.,* AND T. MOCHIZUKI,* "Advanced Neutron Source Design: Burnout Heat Flux Correlation Development," p. 298. (4.18)

KIRK, B. L., AND Y. Y. AZMY, "Hypercube Applications of the XY Geometry Nodal Method for the Neutron Diffusion Equation," p. 104. (5.3)

MAERKER, R. E., "The LEPRICON Code System: Consolidation of Transport Analytical and Unfolding Procedures in LWR Pressure Vessel Dosimetry," p. 225. (3.112)

PRIMM, R. T., III, "Cross-Section Processing Methodology Used to Design the Advanced Neutron Source Reactor," p. 292. (4.26)

RYSKAMP, J. M.,* F. C. DIFILIPPO, AND R. T. PRIMM, III, "Reactor Physics Methods for the Preconceptual Core Design of the Advanced Neutron Source," p. 290. (4.32)

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FLANAGAN, G. F., W. FRAIZE,* AND T. KARTACHAK,* "Risk Associated with the Demilitarization of the United States Chemical Weapons Stockpile." (4.94)

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 "Risk Associated with Operation of the Oak Ridge National Laboratory High
 Flux Isotope Reactor (HFIR)." (4.92)

*IEEE International Workshop on Intelligent Robots and Systems, Tokyo, Japan,
 October 31–November 2, 1988; Proc. (1988)*

PIN, F. G., G. DE SAUSSURE, P. F. SPELT, S. M. KILLOUGH,* AND C. R.
 WEISBIN, "Recent CESAR Research Activities in Sensor Based Reasoning
 for Autonomous Machine," pp. 417–421. (3.33)

*17th Workshop on Applied Imagery Pattern Recognition, Washington, DC, Novem-
 ber 2–4, 1988*

JONES, J. P., AND K. M. CLINARD,* "Parallel Relaxation Matching."
 (3.58)

*Workshop on Design for Computer Experiments, Oak Ridge, TN, November 3–5,
 1988*

CHURCH, A., JR.,* AND T. J. MITCHELL, "Computer Experiments to
 Optimize a Compression Mold Filling Process." (1.87)

DOWNING, D. J., AND S. BARTELL,* "Sensitivity and Uncertainty Anal-
 ysis in Environmental Models." (1.89)

MORRIS, M. D., "Bayesian Design and Analysis of Computer Experiments:
 Use of Derivatives in Surface Prediction." (1.94)

WORLEY, B. A., "Calculation and Use of Computer Model Derivatives."
 (3.88)

*Southeastern-Atlantic Regional Conference on Differential Equations, University of
 Georgia, Athens, GA, November 4–5, 1988*

LENHART, S. M., AND D. G. WILSON, "Changing Domains and a Solidifi-
 cation Problem with Void." (1.59)

*SPIE Conference on Sensor Fusion: Spatial Reasoning and Scene Interpretation,
 Cambridge, MA, November 6–11, 1988; Proc. (1988)*

BECKERMAN, M., J. P. JONES, R. C. MANN, L. A. FARKAS,* AND S.
 E. JOHNSTON,* "Spatial Reasoning in the Treatment of Systematic Sensor
 Errors," Vol. 1003, pp. 338–349. (3.4)

PARKER, L. E., AND F. G. PIN, "Man-Robot Symbiosis: A Framework for
 Cooperative Intelligence and Control," Vol. 1006, pp. 94–103. (3.29)

REISTER, D. B., AND M. W. NOAKES,* "Design of an Obstacle Avoidance
 System for AIMS," Vol. 1006, pp. 124–131. (3.34)

Seminar, Old Dominion University, Department of Mechanical Engineering, Norfolk, VA, November 7, 1988

LAWKINS, W. F., "Curvilinear Coordinates Fitted to a Distorted Annular Region." (1.86)

IEEE 1988 Nuclear Science Symposium, Orlando, FL, November 9-11, 1988; IEEE Trans. on Nuclear Science 37(1) (1989)

GABRIEL, T. A., J. BRAU,* AND B. L. BISHOP,* "The Physics of Compensating Calorimetry and the New CALOR89 Code System," pp. 14-17. (4.48)

ROVERE, L. A.,* P. J. OTADUY, AND C. MARCH-LEUBA, "Development of an Uncertain Model Based Nonlinear Optimal Pressure Control System for a Nuclear Reactor," (did not appear in proceedings). (3.96)

Oral Presentation, State University of New York, Buffalo, NY, November 11, 1988

HEATH, M. T., "Parallel Solution of Sparse Linear Systems." (1.39)

Second International Symposium, Robotics and Manufacturing Research, Education, and Applications, Albuquerque, NM, November 16-18, 1988; Proc. (1989)

DE SAUSSURE, G., C. R. WEISBIN, AND P. F. SPELT, "Navigation and Learning Experiments by an Autonomous Robot," pp. 935-948. (3.13)

NEA Probabilistic System Assessment Codes User Group Meeting, Paris, France, November 29-December 2, 1988

WORLEY, B. A., F. G. PIN, E. M. OBLow, R. E. MAERKER, J. E. HORWEDEL,* AND R. Q. WRIGHT,* "Deterministic Sensitivity and Uncertainty Analysis for Large-Scale Computer Models." (3.90)

Oral presentation, IBM Workshop on Parallel Computing, San Jose, CA, December 4-7, 1988

HEATH, M. T., "Limits to Parallelism." (1.11)

1988 Workshop on Human-Machine Symbiotic Systems (Proceedings), Oak Ridge, TN, December 5-6, 1988

PARKER, L. E., AND C. R. WEISBIN, Editors, "1988 Workshop on Human-Machine Symbiotic Systems." (3.30)

27th IEEE Conference on Decision and Control, Austin, TX, December 7-9, 1988

MARCH-LEUBA, C.,* AND R. B. PEREZ, "Optimal Control of Uncertain Nonlinear Systems: An Application to a Two-Link Robotic Arm." (3.25)

International Workshop on Concurrent Computer Vision, Aalborg, Denmark, January 25-27, 1989

JONES, J. P., "Concurrency in Mobile Robotics at ORNL." (3.54)

JONES, J. P., "The Butterfly Accumulator and Its Application in Concurrent Computer Vision on Hypercube Multicomputers." (3.57)

JONES, J. P., "Concurrent Computer Vision on a Hypercube Multicomputer." (3.55)

Oral Presentation, Statistics Department, The University of Tennessee, Knoxville, TN, January 31, 1989

WRIGHT, T., "Near With Replacement Sampling Without Replacement Using Ranks." (1.117)

NASA Conference on Space Telerobotics, Pasadena, CA, January 31-February 2, 1989

WEISBIN, C. R., B. L. BURKS, J. R. EINSTEIN, R. R. FEEZELL,* W. W. MANGES,* AND D. H. THOMPSON,* "HERMIES-III: A Step Toward Autonomous Mobility, Manipulation and Perception." (3.44)

WATtec Conference, Knoxville, TN, February 16, 1989

REISTER, D. B., "Future Emissions of Carbon Dioxide. Can We Make a Dramatic Reduction?" (3.103)

Oral presentation, Army Survey on High Performance Computing, Washington, DC, February 23-24, 1989

ROMINE, C. H., "Overview of Architectures and Applications in Parallel Processing." (1.16)

Oral presentation, Air Force Office of Scientific Research, Washington, DC, March 1, 1989

WILSON, D. G., AND R. E. FLANERY, "Supercomputer Simulation of a 3-D Melting/Freezing Process." (1.70)

Fourth Conference on Hypercubes, Concurrent Computers, and Applications, Monterey, CA, March 6-8, 1989

CHRISTENSEN, H. I.,* "Concurrent Spatio-Temporal Image Analysis." (3.49)

CHRISTENSEN, H. I.,* AND J. P. JONES, "Concurrent Multi-Resolution Image Analysis." (3.50)

CULIOLI, J.-C., C. W. GLOVER, J. P. JONES, AND C. ROE,* "NCUBE Implementation of Some Heuristics and an Optimal Algorithm for Large-Scale Assignment Problems." (3.64)

EINSTEIN, J. R., C. W. GLOVER, AND M. DICKENS,* "A Tool to Aid in Mapping Computational Tasks to a Hypercube." (3.51)

GEIST, G. A., "Reduction of a General Matrix to Tridiagonal Form Using a Hypercube Multiprocessor." (1.20)

GEIST, G. A., M. T. HEATH, B. W. PEYTON, AND P. H. WORLEY, "A Machine-Independent Communication Library." (1.6)

Oral presentation, NASA Ames Research Center, Moffett Field, CA, March 9, 1989
HEATH, M. T., "Parallel Solution of Sparse Linear Systems." (1.40)

ANS Third Topical Meeting on Robotics and Remote Systems, Charleston, SC, March 13-16, 1989; Proc. (1989)

BECKERMAN, M., L. A. FARKAS,* J. P. JONES, R. C. MANN, AND C. W. GLOVER, "World Modelling and Multi-Sensor Integration for a Mobile Robot," Section 11-2, pp. 1-8. (3.6)

DE SAUSSURE, G., P. F. SPELT, S. M. KILLOUGH,* F. G. PIN, AND C. R. WEISBIN, "Automatic Learning by an Autonomous Mobile Robot," Section 6-1, pp. 1-5. (3.12)

Workshop on Calorimetry for the Superconducting Super Collider, University of Alabama, Tuscaloosa, AL, March 13-17, 1989

ALSMILLER, R. G., JR., F. S. ALSMILLER, T. A. GABRIEL, O. W. HERMANN,* AND J. M. BARNES,* "The High-Energy Transport Code HETC88." (4.36)

GABRIEL, T. A., "CALOR89: The Code System for Calorimeter Analysis and Design." (4.45)

GABRIEL, T. A., "Detectors for the Superconducting Super Collider, Design Concepts, and Simulation." (4.44)

Southeast Atlantic Section of SIAM Meeting, University of Tennessee, Knoxville, TN, March 17-18, 1989

GRAY, L. J., "Boundary Element Method for Regions with Cracks." (1.76)

WILSON, D. G., "An Implicit, Finite Difference, Enthalpy Scheme for Phase Change Problems." (1.66)

Oral Presentation, South Eastern Atlantic Section of SIAM Meeting, Knoxville, TN, March 18, 1989

CULIOLI, J.-C., "Yet Another Non-linear Approach to Linear-Programming." (3.61)

1989 Eastern Multiconference, Tampa, FL, March 28-31, 1989; Proc. Advances in AI and Simulation 20(4) (March 1989)

ROBINSON, J. T., "An Intelligent Simulation Environment for Control System Design," pp. 28-32. (3.91)

Computer Science Seminar, Gainesville, FL, March 30, 1989

ROMINE, C. H., "The Influence of Distributed-Memory Architectures on Linear Algebra Algorithms." (1.32)

SIAM Conference on Optimization, Boston, MA, April 3-5, 1989

WORLEY, B. A., "Calculation and Use of Computer Model Derivatives." (3.88)

International Conference Fifty Years Research in Nuclear Fission, Berlin, West Germany, April 3-7, 1989

MOORE, M. S.,* L. C. LEAL,* G. DE SAUSSURE, R. B. PEREZ, AND N. M. LARSON,* "Resonance Structure in the Fission of ($^{235}\text{U} + n$)." (2.42)

ACM Southeast Region 27th Annual Conference, Atlanta, GA, April 5, 1989; Proc. (1989)

NARANG, H. N.,* AND J. B. DRAKE, "Parallel Solutions of a 2-D Phase Change Problem on a Hypercube," pp. 650-656. (1.60)

Oral presentation, Ohio University, Athens, OH, April 6-7, 1989

DICKENS, J. K., "Neutron Research at the Oak Ridge Electron Linear Accelerator." (2.69)

DICKENS, J. K., "Reactor Safety and the Status of Commercial Nuclear Power in the United States." (2.68)

ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, Santa Fe, NM, April 9-13, 1989; Proc. Vols. 1 and 2 (1989)

AZMY, Y. Y., "Geometrical Shape Optimization of a Cold Neutron Source Using Artificial Intelligence Strategies," Vol. 2, pp. 67:1-67:12. (4.3)

EMMETT, M. B.,* W. A. RHOADES, AND J. O. JOHNSON, "MASH, The Monte Carlo Adjoint Shielding Code," Vol. 1, pp. 42:1-42:10. (4.82)

FU, C. Y., "A Re-Evaluation of $^{32}\text{S}(n,p)$ Cross Sections from Threshold to 5 MeV," Vol. 1, pp. 17:1-17:11. (4.83)

INGERSOLL, D. T., R. W. ROUSSIN, C. Y. FU, AND J. E. WHITE, "Generation of Broad-Group Neutron/Photon Cross-Section Libraries for Shielding Applications," Vol. 1, pp. 21:1-21:9. (4.23)

KIRK, B. L., AND Y. Y. AZMY, "A Parallel Approach to the Nodal Method Solution of the Two-Dimensional Diffusion Equation," Vol. 1, pp. 23:1-23:12. (5.5)

RHOADES, W. A., AND R. E. FLANERY, "3-D Discrete Ordinates Calculations with Parallel-Vector Processors," Vol. 2, pp. 69:1-69:11. (4.30)

TRUBEY, D. K., M. J. BERGER,* AND J. H. HUBBELL,* "Photon Cross Sections for ENDF/B-VI," Vol. 1, pp. 18:1-18:12. (5.16)

8th Symposium on the Training of Nuclear Facility Personnel, Gatlinburg, TN, April 24-27, 1989; Proc. (April 1989)

CARTER, R. J., E. M. CONNELLY,* AND P. A. KROIS,* "Feasibility of Quantitative Performance Measures for Evaluating Nuclear Power Plant Operators," pp. V.A.5.1 - V.A.5.19. (3.120)

American Nuclear Society and National Bureau of Standards Conference on Fifty Years with Nuclear Fission, Gaithersburg, MD, April 26-28, 1989

DIVADEENAM, M.,* T. A. GABRIEL, O. LAZARETH,* M. S. SPERGEL,* AND T. E. WARD, "Production Rates of Cosmogenic Nuclides in Stony Meteorites." (4.42)

LEAL, L. C., G. DE SAUSSURE, AND R. B. PEREZ, "Analysis of the ^{235}U Neutron Cross Sections in the Resolved Resonance Range." (2.39)

PEREZ, R. B., G. DE SAUSSURE, F. C. DIFILIPPO, L. W. WESTON, AND J. A. HARVEY, "Subthreshold and Near-Subthreshold Fission Physics Measurements at the Oak Ridge Electron Linear Accelerator Facility." (2.22)

WESTON, L. W., AND J. H. TODD,* "High Resolution Fission Cross Section Measurements at ORELA." (2.23)

American Physical Society, Baltimore MD, May 1-4, 1989; Proc. Vol. 34(4) (1989)

HUTCHINSON, D. P.,* R. K. RICHARDS,* C. A. BENNETT,* C. C. HAVENER,* C. H. MA,* F. G. PEREY, R. R. SPENCER, J. K. DICKENS, B. D. ROONEY, "A Search for Cold Fusion Neutrons at ORELA." (2.11)

WINTERS, R. R.,* R. F. CARLTON,* AND C. H. JOHNSON,* " $n + ^{40}\text{Ar}$ s- and p-Wave Neutron Resonance Spacings and Strength Functions," p. 1243. (2.25)

2nd International Conference on Trends in Welding Research, Gatlinburg, TN, May 14-18, 1989

ALEXIADES, V., "Shrinkage Effects on Solidification." (1.55)

IEEE 1989 International Conference on Robotics and Automation, Scottsdale, AZ, May 14-19, 1989

MANN, R. C., J. P. JONES, M. BECKERMAN, C. W. GLOVER, L. FARKAS,* AND J. R. EINSTEIN, "Sensor Integration Using Concurrent Computing On-Board the ORNL Mobile Robot." (3.60)

7th Power Plant Dynamics, Control, and Testing Symposium, Knoxville, TN, May 15-17, 1989; Proc. (May 1989)

CARTER, R. J., "Human Factors Aspects of Advanced Instrumentation in the Nuclear Industry," pp. 14.01-14.12. (3.127)

KNEE, H. E., AND J. C. SCHRYVER, "Operator Role Definition and Human System Integration," p. 5.01. (3.121)

ROBINSON, J. T., "An Intelligent Simulation Environment for Control System Design," pp. 3.01-3.12. (3.91)

Workshop on Integration of AI and Robotic Systems, Scottsdale, AZ, May 19, 1989

BECKERMAN, M., D. L. BARNETT,* J. R. EINSTEIN, J. P. JONES, P. F. SPELT, AND C. R. WEISBIN, "Robust Performance of Multiple Tasks by an Autonomous Robot." (3.5)

PARKER, L. E., AND C. R. WEISBIN, "Review of the 1988 Workshop on Human-Machine Symbiotic Systems." (3.31)

Oral Presentation, Annual Banquet of Youngstown State Chapter of Pi Mu Epsilon, Youngstown State University, Youngstown, OH, May 19, 1989

FLANERY, R. E., "A Career as a Working Mathematician - What It's Like to Do It for Real." (1.74)

11th International Conference on Transport Theory, Blacksburg, VA, May 22-26, 1989

PROTOPOPESCU, V., "An Example of a Reaction-Diffusion System with Nonlinear Competitive Interactions." (4.77)

SIAM Symposium on Sparse Matrices, Gleneden Beach, OR, May 22-24, 1989

LEWIS, J. G.,* PEYTON, B. W., AND A. POTHEN,* "A Fast Algorithm for Reordering Sparse Matrices for Parallel Factorization."

NG, E., "A Comparison of Some Methods for Solving Sparse Nonsymmetric Linear Systems." (1.46)

PEYTON, B. W., "A Tie-Breaking Scheme for the Minimum Degree Algorithm."

Oral Presentation, Institute of Atomic Energy, Department of Nuclear Physics, Beijing, China, May 23, 1989

WHITE, J. E., "Multigroup Cross Section Processing Methods Used at Oak Ridge National Laboratory."

Workshop on Cold Fusion Phenomena, Santa Fe, NM, May 23-25, 1989

HUTCHINSON, D. P.,* R. K. RICHARDS,* C. A. BENNETT,* C. C. HAVENER,* C. H. MA,* F. G. PEREY, R. R. SPENCER, J. K. DICKENS, B. D. ROONEY, J. BULLOCK, IV,* AND G. L. POWELL,* "Cold Fusion Neutron Measurements at ORNL." (2.11)

Joint USDOE/Japan Workshop on Fusion Neutronics, Osaka University, Japan, May 24-25, 1989

WHITE, J. E., "Current Activities of RSIC Related to Fusion Neutronics Codes and Data."

The Third International Conference on Genetic Algorithms, Fairfax, VA, June 4-7, 1989; Proc. J. D. Schaffer, Ed., Morgan Kaufmann Publishers, Inc., San Mateo, CA (1989)

PETTEY, C. C.,* AND M. R. LEUZE, "A Theoretical Investigation of a Parallel Genetic Algorithm," pp. 398-405. (1.15)

1989 Annual Summer Meeting of the American Nuclear Society, Atlanta, GA, June 4-8, 1989; Trans. Am. Nucl. Soc. 59 (1989)

DIFILIPPO, F. C., M. ABU-SHEHADEH,* AND R. B. PEREZ, "Two-Point and Two-Energy Group Kinetics Model of the ANS Reactor," p. 347. (4.16)

LEAL, L. C.,* G. DE SAUSSURE, R. R. WINTERS,* AND R. B. PEREZ, "Statistical Properties of the ^{235}U Resonance Parameters up to 300 eV," p. 341. (2.41)

PRIMM, R. T., III, "Reactor Physics Studies of Various Advanced Neutron Source Reactor Core Configurations," p. 346. (4.28)

WRIGHT, R. Q.,* M. L. WILLIAMS,* AND C. O. SLATER, "Impact of ^{235}U (MAT 9235) Evaluation on k_{eff} of Thermal Systems," p. 343. (4.34)

Conference on Expert Systems Applications for the Electric Power Industry, Orlando, FL, June 5-8, 1989

CARTER, R. J., AND R. E. UHRIG,* "Human Factors Issues Related to Expert Systems for Electric Power Plant Control Rooms." (3.129)

8th International Congress of Cybernetics and Systems, Hunter College, New York, June 11-15, 1989

IYENGAR, S. S.,* C. R. WEISBIN, AND F. G. PIN, "Asynchronous Production Systems for Controlling Autonomous Mobile Robots." (3.18)

6th Scandanavian Image Analysis Conference, Oulu, Finland, June 19-22, 1989

BOWYER, K. W.,* J. P. JONES, AND C. H. LAKE,* "Computing the Hough Transform on an MIMD Hypercube." (3.47)

Air Pollution and Waste Management Control Association 82nd Annual Meeting and Exhibition, Anaheim, CA, June 25-30, 1989

G. F. FLANAGAN, W. FRAIZE, W.,* AND T. KARTACHAK,* "Risk Associated with the Demilitarization of the United States Chemical Weapons Stockpile." (4.94)

Oral presentation, Health Physics Society Annual Meeting, Albuquerque, NM, June 25-28, 1989

MORRIS, M. D., "The Role of Assumptions in Statistical Modeling." (1.136)

DOLAN, B. W.,* P. G. GRÖER,* AND V. R. R. UPPULURI, "Characterizing Occupational Dose Distributions Using the Hybrid Lognormal Distribution." (1.125)

Oral presentation, NSF Summer Program for College Students, Mathematics Department, University of Tennessee, Knoxville, TN, June 28, 1989

WRIGHT, T., "Some Basic Concepts in Probability Sampling From a Finite Universe (Population)."

Oral presentation, International Mathematics and Statistical Library, Houston, TX, July 7, 1989

NG, E., "Sparse Partial Pivoting Using Static Storage Schemes." (1.44)

Technology-Based Confidence Building: Energy and Environment, Santa Fe, NM, July 9-14, 1989

REISTER, D. B., "Energy Technology R&D: What Could Make a Difference?" (3.102)

SIAM Annual Meeting, San Diego, CA, July 17-21, 1989

WORLEY, P. H., "Explicitly Parallel Algorithms for Hyperbolic PDEs - A Proof of Principle." (1.49)

1989 ASME Pressure Vessels and Piping Conference, Honolulu, HI, July 23-27, 1989

WEISBIN, C. R., B. L. BURKS, J. R. EINSTEIN, R. R. FEEZELL,* W. W. MANGES,* AND D. H. THOMPSON,* "Research in Autonomous Robotics at ORNL Using HERMIES-III." (3.43)

MIT Workshop on Energy and Environmental Modeling and Policy Analysis, Cambridge, MA, July 31-August 1, 1989

REISTER, D. B., "Energy Technology R&D: What Could Make a Difference?" (3.102)

Oral Presentation, Gordon Research Conference on Statistics in Chemistry and Chemical Engineering, New Hampton, NH, July 31-August 4, 1989

MITCHELL, T. J., AND M. D. MORRIS, "Design and Analysis of Computer Experiments in Chemistry and Chemical Engineering."

1989 National Heat Transfer Conference, Philadelphia, PA, August 6-9, 1989

ALEXIADES, V., "Effect of a Void on Cyclic Melting and Freezing of an Encapsulated PCM." (1.54)

1989 Joint Statistical Meetings, Washington, DC, August 6-10, 1989

HU, P. S.,* WRIGHT, T., AND S.-P. MIADO,* "A Comparative Study of Six Data Sources' Ability for Estimating Interstate Motor Carrier VMT."

MORRIS, M. D., "Factorial Sampling Plans for Preliminary Computational Experiments." (1.93).

OSTROUCHOV, G., AND E. L. FROME, "A Model Search Procedure for Hierarchical Log-Linear Models." (1.115)

American Institute of Chemical Engineers Summer National Meeting, Philadelphia, PA, August 20-23, 1989

CARTER, R. J., "Digital Instrumentation and Interactive Computer Systems: A Survey of the Use of Advanced Technology in the Nuclear Industry." (3.126)

1989 IEEE International Conference on Systems Engineering, Dayton, OH, August 24-26, 1989; Proc. (1989)

MANN, R. C., C. R. WEISBIN, AND F. G. PIN, "Research in Mobile Robotics at ORNL/CESAR," pp. 367-371. (3.23)

Oral Presentation, presented to the Chattanooga Engineers Club, Chattanooga, TN, August 28, 1989

MOSES, D. L., "A Revisit to the Passively-Safe Reactors." (4.96)

European Conference on Mathematics in Industry, Glasgow, Scotland, August 28-31, 1989

GRAY, L. J., G. E. GILES,* J. BULLOCK, IV* AND P. McKENZIE,* "Electroplating Simulation." (1.82)

Eleventh International Conference on Boundary Element Methods, Cambridge, MA, August 29-31, 1989; Proc. Advances in Boundary Elements, Vol. 1, C. A. Brebbia and J. J. Connor, Eds., Computational Mechanics Publications, Boston, MA (September 1989)

GRAY, L. J., "Numerical Experiments with a Boundary Element Technique for Corners," pp. 243-251. (1.78)

47th Session of the Internal Statistical Institute, Paris, France, August 29-September 6, 1989

BOWMAN, K. O., AND L. R. SHENTON,* "Moment Methods and the Gram-Charlier Type A." (1.98)

NOTE: The following meeting is included here because it was erroneously left out of the 1987 Progress Report.

Workshop on Detector Simulation for the SSC, Argonne National Laboratory, August 24-28, 1987

GABRIEL, T. A., F. S. ALSMILLER, R. G. ALSMILLER, JR., B. L. BISHOP,* O. W. HERMANN,* AND J. O. JOHNSON, "CALOR87: HETC87, MICAP, EGS4, and SPECT, A Code System for Analyzing Detectors for Use in High Energy Physics Experiments." (4.47)

GABRIEL, T. A., J. O. JOHNSON, AND J. BRAU,* "MICPAP: A Program for Low Energy Neutron, Ion, and Gamma-Ray Transport and One of Its Applications in Calorimeter Design: Hydrogen Knock-Out as a Method for Achieving Compensation." (4.50)

NOTE: The following meetings/seminars will be held after August 31, 1989. However, since the papers/abstracts were cleared through the Laboratory Records Department before August 31, 1989, they are being included in this report.

'89 IROS International Conference on Intelligent Robot and Systems, "The Autonomous Robot and Its Application," Tsukuba, Japan, September 3-7, 1989

PIN, F. G., M. BECKERMAN, P. F. SPELT, J. T. ROBINSON,* AND C. R. WEISBIN, "Autonomous Mobile Robot Research Using the HERMIES-III Robot." (3.32)

IAEA Consultants' Meeting on Cross Sections for the Generation of Long-Lived Radionuclides, Argonne, IL, September 11-12, 1989

FU, C. Y., "Status of Theories Used for Calculations of Long-Lived Activation Cross Sections." (2.50)

NEANDC Specialist's Meeting on Neutron Activation Cross Sections for Fission and Fusion Energy Applications, Argonne, IL, September 13-15, 1989

FU, C. Y., "A Review of Activation Cross Sections in the ENDF/B-VI General Purpose Files of Cr, Fe, Ni, Cu, and Pb." (2.51)

Sixth Coordination Meeting for the Program to Meet Nuclear Data Needs for Fusion Energy, Athens, OH, September 19-21, 1989

FU, C. Y., "Pairing Corrections and Spin Cutoff Factors in Exciton Level Densities for Two Kinds of Fermions." (2.49)

IAEE 1989 North American Conference, Los Angeles, CA, October 16-18, 1989; Proc. (1989)

REISTER, D. B., "The Replacement Cost Integration Program, An Engineering-Economic Model of Oil Supply," pp. 89-98. (3.108)

33rd Annual Human Factors Society Meeting, Denver, CO, October 16-20, 1989

TERRANOVA, M., R. L. SEAMSTER,* C. E. SNYDER,* AND I. E. TREITLER,* "Cognitive Task Analysis: Techniques Applied to Airborne Weapons Training." (3.119)

17th Water Reactor Safety Information Meeting, Rockville, MD, October 23-25, 1989

CARTER, R. J., "Human Factors Survey of Advanced Instrumentation and Controls." (3.128)

International Symposium on Research Reactor Safety, Operations and Modifications, Canada, October 23-27, 1989

FLANAGAN, G. F., D. H. JOHNSON,* D. BUTTEMER,* AND S. KAPLAN,* "Risks Associated with the Operation of the Oak Ridge National Laboratory High Flux Isotope Reactor (HFIR)." (4.92)

Sensor Fusion II: Human and Machine Strategies SPIE's Advances in Intelligent Robotics, Philadelphia, PA, November 5-10, 1989

GLOVER, C. W., "Design and Implementation of a Multi-Sensor Fusion Algorithm on a Hypercube Computer Architecture." (3.52)

Interservice/Industry Training Systems Conference, Fort Worth, TX, November 16, 1989

SNYDER, C. E.,* N. E. CLAPP, JR.,* D. E. SMITH,* M. TERRANOVA, J. DAVIS,* J. L. FINNEY,* P. G. GUTHRIE,* G. B. PAYNE,* AND S. WEBSTER,* "Teamwork and Data Deliverables: A Map to Software and Training Design Integration." (3.116)

1989 Annual Winter Meeting of the American Nuclear Society, San Francisco, CA, November 26-30, 1989; Trans. Am. Nucl. Soc. 60 (1989)

CARLSON, A. D.,* W. P. POENTITZ,* G. M. HALE,* AND R. W. PEELLE, "The Neutron Cross-Section Standards Evaluations for ENDF/B-VI," p. 604.

HORWEDEL, J. E.,* "GRESS Adjoint Matrix Reduction Algorithms," p. 590. (3.80)

LARSON, D. C., AND P. G. YOUNG,* "Structural and Shielding Material Evaluations for ENDF/B-VI," p. 606. (2.59)

LEAL, L. C.,* G. DE SAUSSURE, R. B. PEREZ, AND R. Q. WRIGHT,* "Test of the ENDF/B Unresolved Resonance Formalism for U-235," p. 620. (2.60)

MAERKER, R. E., P. D'HONDT,* L. LEENDERS,* AND A. FABRY,* "Benchmark Verification of a Method for Calculating Leakage from PLSA Modified Cores," p. 545. (3.113)

MAERKER, R. E., AND B. A. WORLEY, "Development and Application of a New Deterministic Method for Calculating Computer Model Result Uncertainties," p. 591. (3.84)

PEELLE, R. W., "Covariance Data for ENDF/B-VI," p. 608. (2.61)

ROUSSIN, R. W., "Methods and Formats for ENDF/B-VI," p. 617. (5.12)

SAWHNEY, R. S.,* J. C. SCHRYVER, H. E. KNEE, AND H. L. DODDS,* "A Hypothesis Generation Model of Initiating Events for Nuclear Power Plant Operators," p. 179. (3.123)

SMITH, M. S., AND W. A. RAGLAND,* "Interaction of CREDO with EBR-II PRA Development," p. 411. (3.134)

WESTON, L. W., P. G. YOUNG,* AND W. P. POENITZ,* "New Cross Section Evaluations for Reactor Fuel Materials," p. 606. (2.24)

International Meeting on Safety Margins in Criticality Safety, San Francisco, CA, November 26-30, 1989; Proc. (1989)

DIFILIPPO, F. C., "Theoretical Analysis of Reactivity Measurement with the ^{252}Cf Source Ratio Method," pp. 16-23. (4.11)

18th IEEE Conference on Decision and Control, Tampa, FL, December 13-15, 1989

BARNETT, D. L.,* G. DE SAUSSURE, S. S. IYENGAR,* F. G. PIN, A. SABHARWAL,* AND C. R. WEISBIN, "Robot Navigation Research at CE-SAR." (3.1)

International Joint Conference on Neural Networks, Washington, DC, January 15-19, 1990

CULIOLI, J.-C., V. PROTOPODESCU, C. BRITTON,* AND N. ERICSON,* "A Neural Network for Bounded Linear Programming." (3.73)

CULIOLI, J.-C., V. PROTOPODESCU, C. BRITTON,* AND N. ERICSON,* "Neural Networks Models for Linear Programming." (3.72)

1990 HEART Conference, Naval Postgraduate School, Monterey, CA, February 12-16, 1990

JOHNSON, J. O., M. S. SMITH, AND R. T. SANTORO, "Nuclear Weapon Radiation Effects on a Space Based Interceptor Weapon Platform." (4.59)

SANTORO, R. T., J. M. BARNES,* AND J. O. JOHNSON, "The Effects of Natural and Enhanced Van Allen Belt Radiation on a Space Based Weapon Platform." (4.60)

SMITH, M. S., "Material Response to Incident X-Rays." (4.62)

International Society for Optical Engineers, Applications of Artificial Intelligence, Orlando, FL, April 16-20, 1990

BELMANS, P. F. R.,* "An Approach to Elemental Task Learning." (3.8)

International Conference on the Physics of Reactors: Operation, Design, and Computation, Marseille, France, April 23-26, 1990

AZMY Y. Y., AND B. L. KIRK, "Convergence Properties of Iterative Algorithms for Solving the Nodal Diffusion Equations." (4.8)

DE SAUSSURE, G., L. C. LEAL,* AND R. B. PEREZ, "Reich-Moore and Adler-Adler Representations of the ^{235}U Cross Sections in the Resolved Resonance Region." (2.30)

DIFILIPPO, F. C., "Neutron Kinetics of High-Intense Fission Neutron Sources." (4.13)

1990 IEEE Conference on Robotics and Automation, Cincinnati, OH, May 13-18, 1990

BARNETT, D. L.,* AND F. G. PIN, "Robot Navigation Research Using the HERMES Mobile Robot." (3.3)

American Nuclear Society Topical Meeting on Advances in Human Factors Research on Man/Computer Interactions: Nuclear and Beyond, Nashville, TN, June 10-14, 1990

SAWHNEY, R. S.,* AND J. C. SCHRYVER, "An Operator Model-Based Filtering Scheme." (3.122)

SNYDER, C. E.,* AND M. TERRANOVA, "A Part-Task Trainer in the Naval Air System Command." (3.117)

Free Boundary Problems: Theory and Applications Meeting, Center for Research Mathematics, Montreal, Canada, June 13-22, 1990

ALEXIADES, V., AND J. B. DRAKE, "A Weak Formulation for Phase-Change Problems with Bulk Movement Due to Unequal Densities." (1.57)

DRAKE, J. B., AND V. ALEXIADES, "A Convective Flow in the Presence of Melting." (1.58)

Seventh ASTM-EURATOM Symposium on Reactor Dosimetry, Strasbourg, France, August 27-31, 1990

MAERKER, R. E., P. D'HONDT,* L. LEENDERS,* AND A. FABRY,* "Analysis of the VENUS-3 Experiments." (3.114)

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