VOLUME XIV, NUMBER 2

OPTIMINAL ALLOCATION OF SAFEGUARDS INSPECTION RESOURCES FOR A NUCLEAR FUEL CYCLE—Leslie G. Fishbone

U-235 ENRICHMENT DETERMINATION VIA GAMMA SPECTROSCOPY—IMPROVED CALIBRATION AND "UNKNOWN" SAMPLE ASSAY—Alan E. Proctor

COMMUNITY RESPONSE TO LOW-LEVEL RADIOACTIVE WASTE: A CASE STUDY OF AN ATTEMPT TO ESTABLISH A WASTE REDUCTION AND INCINERATION FACILITY—Richard J. Bord, Philip J. Ponzurick, and Warren F. Witzig

NUCLEAR MATERIALS MANAGEMENT

INMM

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

JOURNAL OF THE INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

FEATURE ARTICLES

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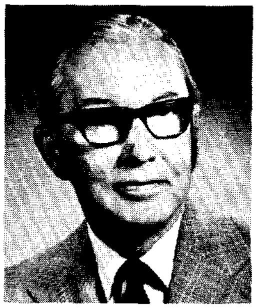
DR. WILLIAM A. HIGINBOTHAM
Brookhaven National Laboratory
Upton, New York



Although non-destructive assay methods had been used for more than a decade, their intensive development and wide acceptance date from January 1967, when the United Kingdom, the Soviet Union, and the United States presented the nuclear nonproliferation treaty for ratification by other nations. It is interesting to consider what progress has been made, since then, in the quality and uses of these valuable techniques.

Non-destructive assay methods were widely used for many purposes and their sophistication and applications continue to expand. As one example of their use for safeguards, I will take gamma-ray spectrometry. As early as 1955, the method was used to measure the U-235 content of MTR fuel plates. Lithium-drifted germanium detectors, linear pulse amplifiers, and thousand channel pulse analyzers were developed in the 1960s. The gamma-ray enrichment measuring technique had been developed.

The reprocessing plant at West Valley, New York, was producing plutonium-nitrate in 1967 and several commercial companies were beginning to fabricate plutonium fuels. There was an urgent need to verify the isotope composition and the amounts of plutonium in the nitrate solutions, in metal coupons for fast critical assemblies, in uranium-plutonium mixed oxides, and a variety of scrap and waste product forms.

Nuclear physicists had studied the energy levels of the radioactive isotopes, including those of uranium, plutonium and americium, so that the energies of most of the gamma-rays which would be useful in safeguards had been published. The "branching-ratios," i.e. the number of gamma-rays of a given energy emitted by one gram of Pu-239 per second, for example, was not so well established. Since these rates are necessary for safeguards, it was necessary for some of those involved in developing safeguards techniques to measure these rates for the several gamma-ray energies of each of the heavy element isotopes of interest. Also, it turned out that the half-lives of the plutonium isotopes and of americium-241 were not known accurately enough. Safeguards budgets for several years supported the necessary research on these two subjects. Now that this technique is being used for ever more accurate isotopic analysis, it may be necessary to invest again in refining the half-life and branching ratio data base.

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CHAIRMAN'S COLUMN

YVONNE M. FERRIS
Rockwell International
Golden, Colorado

In 1979, your Institute established the Long Range Plans (LRP) Committee to formulate a ten-year plan for INMM. The members consisted of V. J. DeVito, T. J. Haycock, W. Hendry, E. R. Johnson, R. Lumb, W. Myre, E. Owings and myself. The committee was ably chaired by Sam McDowell who recently retired, and is now chaired by Glenn Hammond. I would like to share the Committee's recommendations with you and our progress to date.

1. Expand the interest and coverage of INMM to all phases of Nuclear Materials Management to include waste management, transportation and decommissioning sessions in the annual meeting.

   Response: The call for papers includes these topics and the Technical Program Committee Chairman includes invited sessions on these topics. Additionally, several workshops have been conducted on at least two of the expanded topics.

2. Conduct workshops.

   Response: Four workshop committees have been formed. They are:

   —Physical Protection: J. D. Williams
   —Waste Management: E. R. Johnson
   —Material Control and Accountability: D. B. Smith
   —Transportation: J. A. Lamb

   A workshop has been conducted in each of these categories and several have been held on Physical Protection and Waste Management.

3. Continue training programs with the specific objective of qualifying students to become Certified Nuclear Materials Managers.

   Response: A week long training session was held in February, 1984 and a second is scheduled April 21-25, 1986.

4. Increase membership.

   Response: The membership has stayed almost constant at between 700 and 800.

5. Initiate publication of monographs in materials control and accounting, waste management, transportation and decommissioning to enhance member education and stature of INMM, and to disseminate information to the scientific community.

   Response: One monograph was published January 1985 on MC&A, entitled "Safeguarding Nuclear Materials." Another is being prepared by Wendell Weart on waste management. The MC&A monograph was sent to many libraries, to the U. S. Congress, to European governmental bodies and to each member and Journal subscriber of the INMM.

6. Expand subscriptions of INMM Journal and Proceedings to libraries.

   Response: The subscriptions have been expanded slightly, mostly to libraries outside the United States. A plan was adapted at the February 1986 Executive Committee meeting to enhance the Journal and expand its circulation. More about that in the future.

7. Continue to strongly support and expand INMM Standards activities in ANSI N14 and N15 committees.

   Response: The INMM remains Secretariat for N15 and has become Secretariat for N14. These committees are chaired by Obie Amacker and John Arendt, respectively.

8. Maintain sufficient funds in treasury to support INMM activities and Executive Director at least a year in advance.

   Response: Under the supervision of former Treasurer Ed Owings and current Treasurer Bob Curl sufficient funds have been maintained and a five-year budget system, updated annually, has been established.

The Institute is not drifting, merely reacting, or performing in a random manner, as you can see. The Executive Committee is pledged to carry out the recommendations of the LRP Committee. The LRP committee is taking a hard look at the above plan this year to see if it needs to be expanded, reduced or changed in any way. You can be assured that both the LRP and the Executive Committee have the best interests of the Institute in mind when developing and executing plans.

MEMBERSHIP REPORT

ROY CARDWELL
Martin Marietta Energy Systems
Oak Ridge, Tennessee

A COMMITTEE OF 100

All of you have no doubt heard of one or more of the popular active civic groups called a "Committee of 100."

At our last Executive Committee meeting I was given a list of nearly 100 INMM members who had been dropped from membership for non-payment of their dues.

I understand that an organization such as ours is subject to a significant turnover for many reasons, but *this* list contained many names that are not only still very active in the nuclear materials business but also active in the Institute.

The membership fee is still reasonable and does little more than cover our communication costs with you. Just the cost of publishing and mailing the Journal, the Annual Meeting Proceedings, and the various materials that keep you up to date on all of our activities comes to a total of $38 per member. So a good 85% of your membership fee comes back to you in hard copy of valuable technical articles and current information.

And these are just a portion of the benefits. With all the other assets, there's more "bang for your buck" than any other technical service you can find.

IT'S NOT TOO LATE TO REINSTATE !!

We hope you will reconsider.

VICE CHAIRMAN'S REPORT

CHARLES M. VAUGHAN
General Electric Company
Wilmington, North Carolina

The Vice Chairman's attention, as well as a number of your fellow members, has been focused toward organizing and pulling together the program for our annual meeting in New Orleans, June 22-25, 1986.

The theme for the meeting "Success in Integrated Safeguards" is a very timely topic. Clearly, in today's environment where we as safeguards professionals face new and tougher technical challenges coupled with extreme pressures to reduce costs, creative ways to accomplish our objectives are a must. This means building on the strengths of all our systems, eliminating weaknesses, and emphasizing implementation. We are in a time of change and a time of challenge.

Those of us working on the program this year feel an extreme challenge. The Albuquerque meeting was the largest and most comprehensive meeting in INMM's history. It was also the best attended. Given the new goals which we must now measure ourselves against and the professional challenges of the nuclear field, the Institute's work is clearly cut out for us. We need each member to help support this effort.

New Orleans will be an excellent host for the meeting. The facilities nicely support the type of conference we have planned. Charlie Pietri, Dennis Mangan, Jim Hamilton, Gary Carnivel and Roy Cardwell, along with a number of other key individuals, are working very hard and are pulling together a superb program for the meeting. Expect some new and different aspects to the program. Most of all, make your plans early to meet with us and take part in the excellent exchange of information and technology related to nuclear activities around the world.

CENTRAL REGION CHAPTER REPORT

The Central Region Chapter has elected a new Executive Committee. Approximately 60 members returned ballots in the fall election, with the following results. William Mee was elected Chairman; Homer Faust, Vice Chairman; Donald Fidler, Secretary; and John Wachter, Treasurer. Executive Committee Members at Large are: John Arendt, Steven Combs and Garland Proco. Past Chairman is John Lemming.

TECHNICAL PROGRAM FOR THE INMM ANNUAL MEETING

CHARLES E. PIETRI
U.S. Department of Energy
Argonne, Illinois

Excellent progress is being made in developing the technical program for the INMM Annual Meeting, June 23-25, 1986, in New Orleans. We plan to have an exciting plenary session with noted speakers addressing topics as IAEA safeguards, DOE perspectives, NRC highlights, nuclear industry initiatives, waste management mission plan and our usual (unusual) "sparkler" surprise topic! (Remember Cordell Reed, John Graham — — —!) So in order to bring you a vital, current, and novel plenary session, we postpone locking in the actual program until the last moment.

If you believe that, then maybe you will also accept our challenge to top last year's outstanding Annual Meeting performance. It is not too late to promote the Annual Meeting among colleagues, associates, friends and strangers. Most attendees of our meetings have gone away with an enlightened view of safeguards, nuclear materials management, waste management, and transportation just from the great variety of topics presented. The meeting can also be a great forum for substantial personal interaction as well as technology transfer; in other words, discovering what's *really* going on!

Several significant areas of interest will be explored in this year's meeting: revelations about MC&A inspection activities; new approaches to the insider threat; a great transportation session; several successful measurement applications for reprocessing; real world results from measurement control; novel practical applications of physical security; safeguards; and the utilities' challenge. And many more!

At this writing, the phones are ringing, telegrams are being slipped under the door, telecopies are appearing everywhere—and even the regular mail is piling up. Such activity means that we will have a lot of outstanding papers of significant interest to everyone at the Annual Meeting! Start making your plans to attend now to enjoy another INMM success.

For additional information or inspiration (no problems please!) contact Charles Pietri at FTS 972-2449 (Commercial 312:972-2449).

IN MEMORIAM LIVY FERRIS

Livingston P. Ferris II (Livy), died on December 22, 1985 of a heart attack. Prior to his retirement in 1983 Livy was in Safeguards as Shift Superintendent at the Rockwell International Rocky Flats Plant in Colorado. He had been at Rocky Flats for 31 years and had held positions in production, quality and safeguards. He had been a member of INMM for six years and was best known to the Institute in his capacity as Annual Meeting Photographer.

SAFEGUARDS COMMITTEE REPORT

LEON D. CHAPMAN
Chairman, Safeguards Committee
BDM Corporation
Albuquerque, New Mexico

The INMM Safeguards Committee met with R. Burnett, Director, Division of Safeguards (NMSS), U.S. Nuclear Regulatory Commission and his staff on December 12, 1985.

The NRC presented information on the current status of the Insider Rule, Non-Power Reactor Rules, MC&A Reform Amendment, LEU Rule, Waste Management and Spent Fuel Transportation.

The main issue discussed with NRC in the afternoon Safeguards Committee meeting was the question of INMM participation as the interface between the utilities and the FBI for criminal history background information. Industry and NRC need an organization to provide the service. It is one of passing requests for criminal history from the utilities to the FBI and returning the information. There would not be any personnel information retained by the interface organization other than transaction information (date, name, etc.). Both the NRC and several utilities would like to have INMM serve this interface role.

The formal Congressional law requiring this interface is currently in Congress and should be implemented in the next three to four months. Other alternatives may be available to industry, but no one has stepped forward at this time. The INMM Executive Committee voted during their Board Meeting in February to commit INMM for consideration as a candidate to serve as this interface.

N14 COMMITTEE REPORT

JOHN W. ARENDT
Chairman, N14 Committee
JBF Associates, Inc.
Knoxville, Tennessee

Chairman John W. Arendt presented a paper on N14 activities at the DOE Radioactive and Hazardous Materials Packaging workshop held October 28-31, 1985, in Knoxville, Tennessee.

Mr. Arendt will also be representing N14 interests in several upcoming meetings:

- Nuclear Standards Board, March 1986, Atlanta.
- PATRAM '86, June 16-20, 1986, Davos, Switzerland.
- DOE's Annual Radioactive and Hazardous Materials Workshop, October 1986.

The Management Committee met on January 9 and 10, 1986, in Knoxville, Tennessee, and a major item on the agenda was the status of the N14.8 Scope Committee. The Scope Committee concluded that comprehensive voluntary standards for spent fuel and high level waste packaging are neither appropriate nor feasible. A Peer Review Panal, managed by N14, has been proposed and informally accepted by DOE.

In standards:

- The ANSI.24-1985 "American National Standard for Highway Route Controlled Quantities of Radioactive Materials—Domestic Barge Transport," has been published and is available for distribution. Copies can be purchased from ANSI for $15 a copy, plus a shipping and handling charge.
- Dave Smith ISO/TC 85 has made initial contact about utilizing ANSI.5 "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials" as the basis for an international standard.

Status of Standards:

(1) Four draft standards are in the process of ANSI approval and publication (N14.1, N14.6, N14.19, N14.27).

(2) Three draft standards have balloting complete and negative comments are being resolved (N14.5, N14.23, N14.29).

(3) Three draft standards are to be reballoted (N14.2, N14.9.2, N14.10).

(4) Six proposed standards are in various draft stages (N14.3, N14.7, N14.10.1, N14.20, N14.25, N14.28).

(5) One standard is inactive (N14.26).

(6) One standard is to be withdrawn (N14.4).

(7) One standard is awaiting N14.8 Ad Hoc Committee recommendations (N14.8).

A complete status report of ANSI N14 standards indicating designations, titles, N14 coordinators, working group chairmen, scope approval and comments is presented on pages 8 and 9 of this Journal.

IN MEMORIAM ARNIE WOLVENDYK

Arnie Wolvendyk, 38, a five year member of the Institute and a Certified Safeguards Specialist died January 21, 1986 after a lengthy illness. Arnie had been employed at UNC Naval Products and was active in Nuclear Materials Management and Control for ten years.

INMM CALENDAR OF EVENTS

MARCH 17-20, 1986
Security Force Training Workshop
Clarion Hotel
Albuquerque, NM

Chairman
James D. Williams

APRIL 21-25, 1986
Shortcourse on Safeguards
Certification
Brookhaven National Laboratory
Upton, NY

JUNE 22-25, 1986
27th Annual Meeting
The Fairmont Hotel
New Orleans, LA

Chairman
Charles M. Vaughan

OCTOBER, 1986
Physical Protection Workshop on
Information Display and
Control Systems

Chairman
James D. Williams

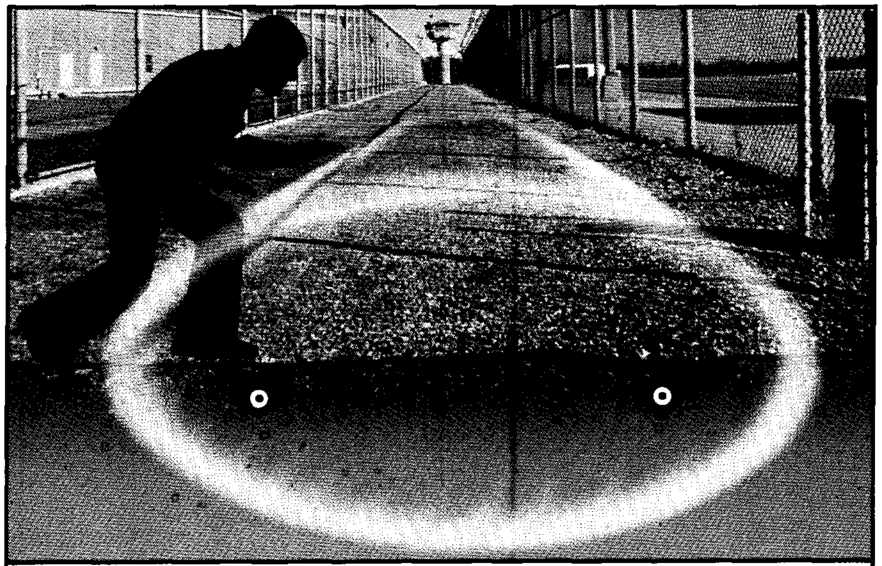
JANUARY 20-23, 1987
Spent Fuel Storage Seminar
Loew's L'Enfant Plaza
Washington, DC

TO BE ANNOUNCED
Decontamination and Decommissioning
Seminar
Hyatt Regency Washington
on Capital Hill
Washington, DC

Chairmen
E.R. Johnson
John A. McBride

TO BE ANNOUNCED
Shortcourse on Safeguards
Certification

Chairman
Barbara M. Wilt



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ANSI N14 STATUS REPORT OF STANDARDS

STD DESIGNATION	TITLE	N14 COORDINATOR	WORKING GROUP CHAIRMAN	SCOPE APPROVED	STATUS/DATE DRAFT	STATUS/DATE BALLOT	STATUS/DATE BSR	COMMENTS
N14.1	Packaging of Uranium Hexafloride for Transport	Arendt	R. I. Reynolds	X	X	03/85	02/86	
N14.2	Tiedowns for Transport of Fissile and Radioactive Containers Greater than One-Ton Truck Transport	Lee	R. Towell	X	under revision			revised as result of negative ballot. expect for reballot 02/86
N14.3	Packaging and Transportation of Radioactively Contaminated Biological Materials	Welch	W. J. Walker	developing draft				N14 will ballot on scope
N14.4	Quality Assurance in the Fabrication, Use and Maintenance of Shipping Containers for Radioactive Materials	Welch	—					N14 will vote on dropping per Ad Hoc Recommendation
N14.5	Leakage Tests on Packages for Shipment of Radioactive Materials	Arendt	L. E. Fischer	X	X	11/85		one negative vote to be resolved
N14.6	Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500kg) or More for Nuclear Materials	Lee	G. Townes	X	X	X	X	waiting ANSI approval
N14.7	Guide to the Design and Use of Shipping Packages for Type A Quantities of Radioactive Materials	Lee	D. Edling	X	X			expect soon for N14 ballot
N14.8	Fabricating, Testing, and Inspection of Shielded Shipping Casks for Irradiated Reactor Fuel Elements	Eggers	D. Dawson					committee recommends suspension until Peer Review Panel recommends new std.—DOE will be sole user
N14.9.2	Packaging of Nuclear Power Plant Radioactive Processed Wastes for Transportation	Tarnuzzer	P. Mayo	X	X	X		changes as result of negative ballot; will be reballoted by N-14
N14.10	Guide for Liability and Property Insurance in Shipping Nuclear Materials	Tarnuzzer	J. Quattrocchi	X				revised as result of negative ballot. expect new draft mid February 1986
N14.10.1	Administrative Guide for Packaging and Transporting Radioactive Materials	Tarnuzzer	D. Edling	X				expect draft in July 1986
N14.19	Ancillary Features of Irradiated Fuel Shipping Casks	Eggers	K. Goldman	X	X	X		resolving one negative ballot
N14.20	Control of Contamination of Transport Vehicles	Lee	L. Jackson	X				revised draft by March 1986
N14.23	Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One Ton in Truck Transport	Eggers	D. Ahlbeck	X	X	X		one negative ballot; review change and determining if reballot needed

ANSI N14 STATUS REPORT OF STANDARDS

STD DESIGNATION	TITLE	N14 COORDINATOR	WORKING GROUP CHAIRMAN	SCOPE APPROVED	STATUS/DATE DRAFT	BALLOT	BSR	COMMENTS
N14.24	Barge Transport of Radioactive Materials	Eggers	E. Wilmot	X	X	X	X	published
N14.25	Tiedowns for Rail Transport of Fissile and Radioactive Material	Lee	R. Towell					waiting on completion of 14.2
N14.26	Inspection and Preventative Maintenance of Packaging for Radioactive Materials	Arendt	–					inactive
N14.27	Carrier and Shipper Responsibilities and Emergency Response Procedures for Highway Transportation Accidents Involving Truckload Quantities of Radioactive Material	Lee	P. McCreery	X	X	X	02/86	ready to be submitted
N14.28	Carrier and Shipper Responsibilities and Emergency Response Procedures for Highway Transportation Accidents Involving less than Truckload Quantities of Radioactive Materials	Tarnuzzer	S. Wawrzaszek					new chairman still forming committee
N14.29	Guide for Writing Operating Manuals for Radioactive Materials Packaging	Arendt	R. Waite	X	X	X		Negative ballots being resolved

NOMINATING COMMITTEE ANNOUNCES SLATE OF CANDIDATES FOR FY87 ELECTION

In connection with the INMM Executive Committee meeting held in Chicago, February 11-12, 1986, Nominating Committee Chairman G. Robert Keepin announced the slated candidates for FY87. The slate is as follows:

Chairman:
Charles M. Vaughan—General Electric Company

Vice Chairman:
John F. Lemming—Monsanto, Mound Laboratory
Dennis W. Wilson—Rockwell Hanford

Secretary:
Vincent J. DeVito—Goodyear Atomic Corporation

Treasurer:
Robert U. Curl—EG&G Idaho

Executive Committee Members at Large:
John Barry—Mid-South Utilities
Ralph E. Caudle—Wackenhut Corporation
Dennis L. Mangan—Sandia National Laboratories
Jeorg H. Menzel—U.S. State Department
Darryl B. Smith—Los Alamos National Laboratory

Members of the Nominating Committee include G. Robert Keepin, Chairman—Los Alamos National Laboratory, Roy G. Cardwell—Martin Marietta Energy Systems, John L. Jaech—International Atomic Energy Agency, E.R. Johnson—E.R. Johnson Associates, Charles E. Pietri—USDOE, Chicago Operations and Glenn A. Hammond—USDOE/OSS.

INMM 1985-86 EXECUTIVE COMMITTEE

CHAIRMAN Yvonne M. Ferris
VICE CHAIRMAN Charles M. Vaughan
SECRETARY Vincent J. DeVito
TREASURER Robert U. Curl
MEMBERS AT LARGE
John F. Lemming
G. Robert Keepin
James P. Shipley
Nancy M. Trahey
Dennis W. Wilson

1985-86 COMMITTEE CHAIRMEN

Annual Meeting Arrangements	Dennis L. Mangan
Annual Meeting Exhibits	James C. Hamilton
Annual Meeting Technical Papers	Charles E. Pietri
Annual Meeting Local Arrangements	H. M. Leith
Annual Meeting Registration	Gary Carnival
Awards	Ralph E. Caudle
Bylaws & Constitution	Roy G. Cardwell
Certification	Barbara M. Wilt
Communications	William A. Higinbotham
Education	James W. Tape
Examining	James E. Lovett
Headquarters & Journal	John E. Messervey
Journal Technical Editor	William A. Higinbotham
Long Range Planning	Glenn A. Hammond
Membership	Roy G. Cardwell
Material Control & Accounting TWG	Darryl B. Smith
N-14 Standards	John W. Arendt
N-15 Standards	Obie P. Amacker, Jr.
Public Awareness	Richard F. Duda
Physical Protection TWG	James D. Williams
Safeguards	Leon D. Chapman
Training Coordinator	Dean D. Scott
Transportation TWG	John A. Lamb
Waste Management TWG	E. R. Johnson

1985-86 CHAPTER CHAIRMEN

Central	William T. Mee
Pacific Northwest	Richard A. Schneider
Southeast	Wendell L. Belew
Japan	Ryohei Kiyose
Vienna	Joseph Nardi

INMM STAFF

Executive Director	John E. Messervey
Administrator	Beth Perry
Accounting Services	Carol Vraney

TECHNICAL WORKING GROUP ON PHYSICAL PROTECTION

JAMES D. WILLIAMS
The WLS Group
Albuquerque, New Mexico

The Technical Working Group on Physical Protection sponsored another technical workshop on Security Force Training, March 17-20, 1986, at the Albuquerque Clarion Hotel. Program Chairman Fredrick Crane, International Energy Associates, and Co-chairm Dennis C. S. Wilson, DOE Central Training Academy, put together an outstanding program which focused on the qualification, training, operations and evaluation of security forces for federal and sensitive commercial sector facilities.

The opening general session featured keynote speakers who set the stage for the sessions to follow. The participants and their topics:

- **DOE Field Office Perspective**
  Mr. George Miserandino, Director
  Office of Safeguards and Security
  DOE Savannah River Operations Office
- **Security Force Perspective**
  Mr. Harry Leith, Project Manager
  Wells Fargo Guard Services
  DOE Strategic Petroleum Reserve
- **NRC Perspective**
  Mr. Robert Nulsen, Section Chief
  Division of Safeguards
  U.S. Nuclear Regulatory Commission
- **Nuclear Utility Perspective**
  Mr. Joseph Brennan
  Nuclear Security Director
  Commonwealth Edison
- **DOE Central Training Academy**
  Mr. Dennis Wilson, Deputy Director
  DOE Central Training Academy

The balance of the workshop featured twelve session topics which were discussed in small groups, providing the opportunity to present, discuss and exchange information, ideas and insights on the latest developments in security force training and tactics.

Attendees also participated in a guided tour of DOE's new Central Training Academy in Albuquerque.

The closing general session featured a discussion of DOE's Cerberus Program by Michael Seaton, Director of the Office of Safeguards and Security at DOE Headquarters.

TECHNICAL WORKING GROUP ON MATERIALS CONTROL AND ACCOUNTING

DARRYL B. SMITH
Los Alamos National Laboratory
Los Alamos, New Mexico
JAMES W. TAPE
Los Alamos National Laboratory
Los Alamos, New Mexico

The TWG on Materials Control and Accounting sponsored a workshop on The Propagation of Error for Nuclear Materials Accounting, January 22-24, 1986, at the Loew's L'Enfant Plaza in Washington, D.C. The workshop was organized and carried out by co-chairmen James P. Tape, Los Alamos National Laboratory and Stephen M. Baloga (Jet Propulsion Laboratory, formerly DOE/OSS). Attendance was slightly over 70, including six from Europe and Japan.

The workshop featured talks by experts in various areas of error propagation for nuclear materials accounting followed by discussion groups relating to topics covered in the presentations. Introductory remarks by representatives from the DOE and NRC helped set the stage for attendees, most of whom were from DOE facilities or NRC licensed plants.

Richard Picard, Los Alamos National Laboratory, gave the first technical presentation, reviewing the fundamental theory of error propagation as it relates to nuclear materials accounting and pointing out some of the difficulties presented by unmeasured and often unknown contributors to the material balance variance. The question of how to deal with non-measurement contributors (that is, to model, use historical data, ignore, etc.) was a topic of continuing debate and discussion throughout the workshop.

The second technical presentation concerned error propagation tools. Jonathan Sanborn, Brookhaven National Laboratory, reviewed a representative selection of codes (EPIC, INSPECT, DECANAL, and PSIG) and Jody Giacomini, Rockwell-Rocky Flats, described her experiences using AMASS. There are a number of codes, ranging from the simple to the complex, available for use in estimating materials balance variance with corresponding degrees of accuracy. Two schools of thought emerged from the discussions regarding codes. One held that the basic equations are known and each user should develop his own code customized to his needs; whereas the other felt that standard codes with software interfaces to match with each facilities' data-base were desirable. The auditability of codes that are used to generate alarm limits was discussed. Codes are also helpful in performing rapid sensitivity analyses to determine the major contributors to the ID variance.

The third presentation was given by a team from Martin Marietta Energy Systems, Y-12, consisting of Denise Schmoyer, R.G. McMillan, and Jeffrey Zollar. They discussed information requirements for error propagation including the role of measurement control programs, the potential importance of biases, and the difficulty and importance of estimating holdup in operating facilities. Obtaining all of the information required for a complete error propagation analysis for real operations is a formidable task, and deciding what to do about unmeasured contributors remained a hot topic of discussion.

Thursday afternoon was devoted to participants sharing their experiences and views on error propagation. Donald Emon, DOE/OSS; Nick Roberts, Los Alamos National Laboratory Rockwell; Barbara Greer, Rockwell-Rocky Flats; Albert Liebetrau, Battelle Pacific Northwest Laboratories PNL; F. Argentisi, ISPRA; and Gary Kodman, Rockwell Hanford all gave informative, informal presentations.

The workshop concluded on Friday morning with a summary discussion that included many of the issues outlined above. Error propagation is seen as a useful and important tool in materials accounting that can be used to help allocate resources to measurement (or non-measurement) problems and to estimate realistic alarm limits.

TECHNICAL WORKING GROUP ON RADIOACTIVE WASTE MANAGEMENT

E.R. JOHNSON, CHAIRMAN
E.R. Johnson & Associates, Inc.
Reston, Virginia

The Technical Working Group on Waste Management presented its third annual seminar on Spent Fuel Storage, January 22-24, 1986, at the Loew's L'Enfant Plaza in Washington, D.C. A total of 25 papers were presented at the seminar and an extensive question and answer/discussion period at each session addressed the key technical and institutional issues related to spent fuel storage. One hundred people attended the informative three-day program.

The proceedings contents which follow, testify to the relevant exchange of ideas, information and data on all aspects of the spent fuel storage problem. Copies of these proceedings are available from INMM headquarters ($200 a copy).

Dry Storage Modules

SESSION CHAIRMAN: E.R. Johnson—E.R. Johnson Associates, Inc.
CASTOR V SPENT FUEL CASK—1985-1986 STATUS UPDATE
Robert T. Anderson, Victor J. Barnhart—General Nuclear Systems, Inc.

THE NAC S/T STATUS—AN UPDATE
John V. Houston—Nuclear Assurance Corporation

BWR CASK CHARACTERIZATION TEST PROGRAM AT THE MORRIS OPERATION
J.W. Doman—General Electric Company

Spent Fuel Disassembly and Rod Consolidation

SESSION CHAIRMAN: James B. Moegling—TVA

AT REACTOR STORAGE EXPANSION OPTIONS
Anton A. Fuierer—Rochester Gas and Electric Company

WATER POOL CONSOLIDATION PROGRAM AT WEST VALLEY AND BROWNS FERRY
Charles R. Johnson—Nuclear Assurance Corporation

NOVEL APPROACH TO ROD CONSOLIDATION
William J. Wachter—US Tool and Die Corporation, Inc.

SPENT FUEL CONSOLIDATION BY SINGLE ROD TRANSFER
Dennis J. Hallahan—Proto-Power Corporation

DISPOSAL SYSTEM INCENTIVES FOR THE AT-REACTOR CONSOLIDATION OF SPENT NUCLEAR FUEL
N. Barrie McLeod—E.R. Johnson Associates, Inc.

THE NUSCO/FUEL CONSOLIDATION PROGRAM—A PROGRESS REPORT
Robert Isakson—Northeast Utilities Service Company

Technical Issues and Programs

SESSION CHAIRMAN: John A. McBride—E.R. Johnson Associates, Inc.

UTILITY/DOE COOPERATIVE AGREEMENTS FOR SPENT FUEL STORAGE
Gordon H. Beeman—Pacific Northwest Laboratory

SPENT FUEL BEHAVIOR IN VARIOUS STORAGE MODES
A.B. Johnson, Jr., W.J. Bailey, E.R. Gilbert—Pacific Northwest Laboratory

A NEW LOOK AT SPENT FUEL POOL LOADINGS
Burton F. Judson, John E. VanHoomissen—General Electric Company
Ray E. Hoskins, James B. Moegling—Tennessee Valley Authority

TVA SYSTEMS STUDY
Raymond E. Hoskins—Tennessee Valley Authority

Results of PRDA Studies

SESSION CHAIRMAN: Carl Connor—US Department of Energy

AN ASSESSMENT OF THE USE OF HALF—SQUARE CANS ON THE MANAGEMENT OF SPENT FUEL
Yong M. Park, Colin A. Heath—NUS Corporation
B. Barrie McLeod—E.R. Johnson Associates, Inc.

EVALUATION OF METAL CASK SYSTEMS
James H. Saling—Westinghouse Waste Technology Services Division

A STUDY OF EXTRA LARGE STORAGE CASKS
Paul N. McCreery—TransNuclear, Inc.

UNIVERSAL CANISTER CONCEPT FOR SPENT NUCLEAR FUEL STORAGE, TRANSPORTATION AND DISPOSAL
R.P. Morissette—GA Technologies, Inc.

CENTRAL DISASSEMBLY AND PACKAGING OF SPENT FUEL
E.R. Johnson—E.R. Johnson Associates, Inc.

The DOE Monitored Retrievable Storage (MRS) Program

SESSION CHAIRMAN: J.H. Carlson—US Department of Energy

DESCRIPTION OF MRS DESIGNS AND COSTS
J.H. Carlson—US Department of Energy

LICENSING OF DRY INDEPENDENT SPENT FUEL STORAGE INSTALLATIONS AND MONITORED RETRIEVABLE STORAGE FACILITY
Fritz Sturz, John P. Roberts—US Nuclear Regulatory Commission

REPORT ON THE MRS/REPOSITORY INTERFACE TASK FORCE ACTIVITIES
Carl W. Connor—US Department of Energy

NUCLEAR ENERGY ISSUES—99TH CONGRESS
Ed Davis—American Nuclear Energy Council

These topics will be expanded on in the '87 Spent Fuel Storage Seminar, to be held January 20-23, 1987, at Loew's L'Enfant Plaza in Washington, D.C. Participants can again expect to learn first hand of the programs being pursued in the United States and other countries and the status of the development projects in spent fuel storage technology.

N15 STANDARDS COMMITTEE

OBIE P. AMACKER, JR.
Chairman, N15 Committee
Battelle Pacific Northwest Laboratories
Richland, Washington

The N15 standards assessment is continuing.

These three standards are currently out for review:

N15.10-1972—Classification of Unirradiated Plutonium Scrap.
N15.18-1975—Mass Calibration Techniques for Nuclear Material Control.
N15.20-1975—Guide to Calibrating Nondestructive Assay Systems.

A request for an extension has been submitted to ANSI for N15.23-1979—Guide to the Nondestructive Assay of 235-U Content of Unpoisoned Low-Enrichment Uranium Fuel Rods. The request for an extension through July 1986 went out for ballot January 10, 1986.

Through correspondence with ANSI, the committee ascertained the steps necessary to complete the formal withdrawal of N15.3-1972—Physical Inventories of Nuclear Materials. The subcommittee chairman responsible for the standard is following through to complete the withdrawal.

Copies of the recently published Style Manual from ANSI were distributed to the N15 Subcommittee Chairman in December.

JOURNAL ARTICLE DEADLINES

Deadlines for technical manuscripts (requiring review) and news articles, etc. (not requiring technical review) are given in the annual schedule noted below. As a convenient reminder to colleagues in your organization, you may wish to post this schedule.

Issue	Technical* Manuscripts Due	News** Articles, etc. Due	Publication Mailing Date
Number 1	January 19	January 19	March 1
Number 2	April 19	April 19	June 1
Number 4	October 19	October 19	December 1

*To submit a technical article (requiring review), send three copies to Dr. William A. Higinbotham, TSO, Building 197, Brookhaven National Laboratory, Upton, Long Island, New York 11973 (phone 516/345-2908, or FTS 666-2908). One copy should be sent to Editor, NUCLEAR MATERIALS MANAGEMENT, INMM Headquarters, 60 Revere Drive, Northbrook, Illinois 60062, U.S.A. (phone: 312/480-9573).

**News articles, photos (with captions, of course), book reviews, summaries of technical presentations, guest editorials, technical notes, etc. should be submitted by the appropriate deadline to the Editor at INMM Headquarters.

SAFEGUARDS CERTIFICATION PROGRAM REPORT

BARBARA M. WILT
Chairman, Certification Committee
Westinghouse Electric Corporation
Columbia, South Carolina

The Safeguards Short Course will be offered annually at various locations throughout the United States. In conjunction with the course, the Safeguards Certification Examination will be administered to those course participants desiring to participate. Additionally, the Safeguards Certification Examination is offered at the Annual INMM Meeting each summer. Long range plans for the short course and annual meetings are shown in the attached table.

Special requests for the certification exam can be honored when circumstances are reviewed and approved by the INMM Certification Board. Arrangements to give the examination in locations outside of the United States can be provided with advanced notification.

To participate in the certification program, applicants must fulfill the certification education/experience requirements. Current examination fees are $250 (specialist) and $100 (intern). Short course fees include the examination fee regardless of whether the participant elects to take the examination or not.

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INMM SUSTAINING MEMBERSHIPS

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Los Alamos National Laboratory
RCA Government Communications Systems
Rockwell International, Rocky Flats Plant
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Uranium Enrichment Corporation
URATOM
E.R. Johnson Associates

Sustaining member contributions are based upon the total number of corporate employees. Annual dues are as follows:

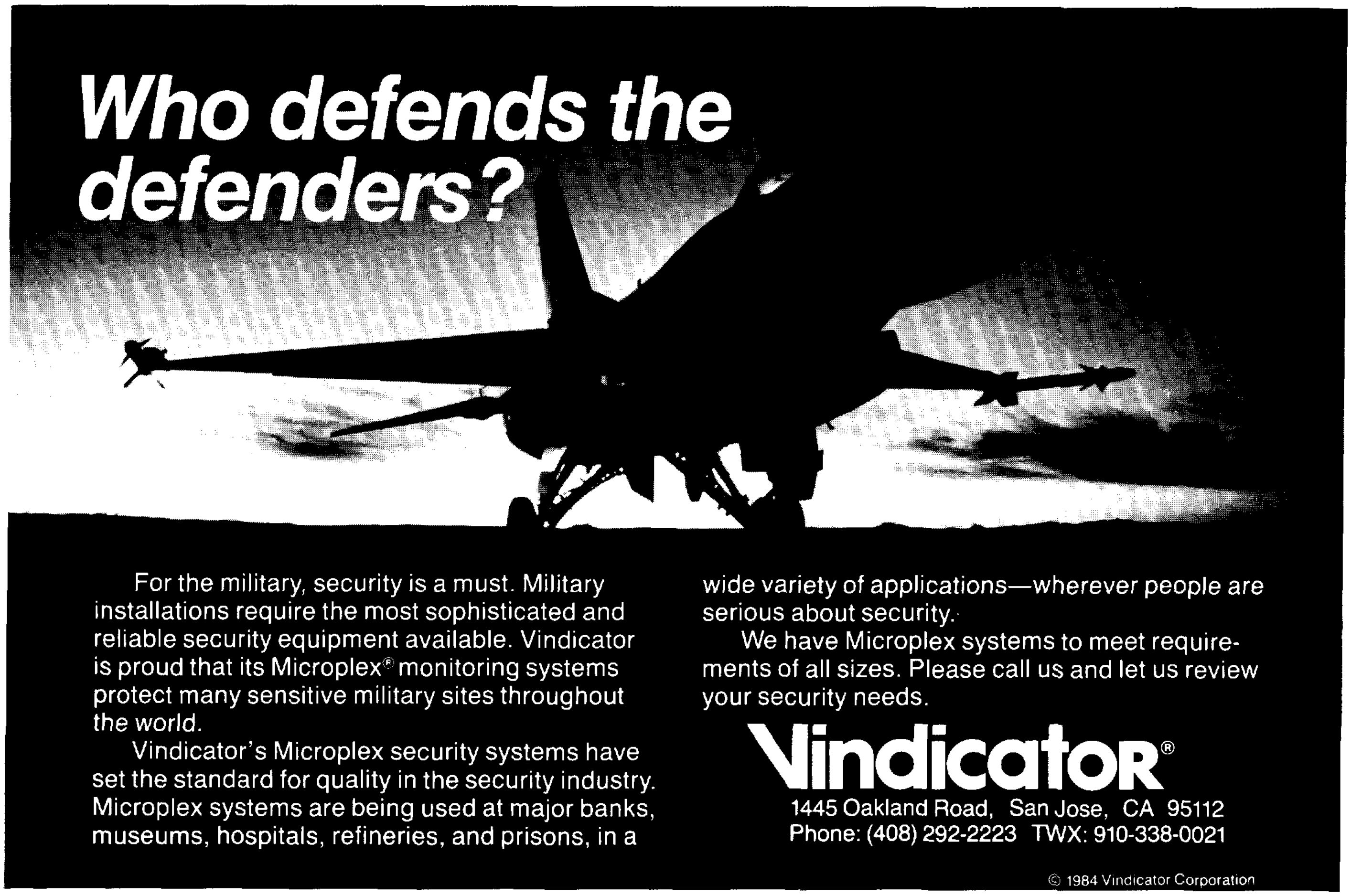
Total Number of Corporate Employees	Annual Dues
0-19	$250.00
20-49	$500.00
50 or more employees	$750.00

In order to join as a Sustaining Member, contact Beth Perry at INMM headquarters for an application.

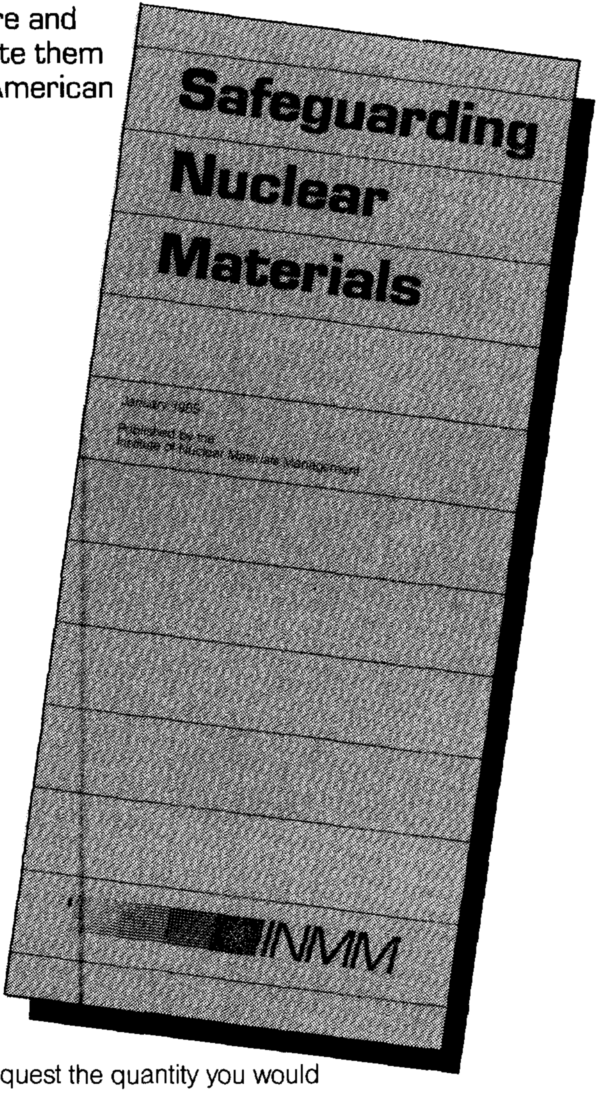
SAFEGUARDS CERTIFICATION PROGRAM LONG RANGE PLANS

TOPIC/SUBJECT	**1986**	**1987**	**1988**	**1989**	**1990**
SAFEGUARDS SHORT COURSE					
DATE	April 21-25	February	February	February	February
EXAMINATION REGISTRATION DEADLINE	March 20	January 15	January 15	January 15	January 15
LOCATION	New York (Long Island)	Tennessee (Oak Ridge)	Colorado (Denver)	Florida (St. Petersburg)	Georgia (Atlanta)
FEE (*SUBJECT TO CHANGE)	$500.00 (includes examination fees)	$500.00* (includes examination fees)	$550.00* (includes examination fees)	$550.00* (includes examination fees)	$550.00* (includes examination fees)
PLACE	Brookhaven National Laboratory	T.B.E.	T.B.E.	T.B.E.	T.B.E.
ANNUAL INMM MEETING					
DATE	June 22-25	Summer (June/July)	Summer (June/July)	Summer (June/July)	Summer (June/July)
EXAMINATION REGISTRATION DEADLINE	May 15	May 15	May 15	May 15	May 15
LOCATION	Louisiana (New Orleans)	Washington (Seattle)	U.S. Capitol (Washington DC)	California (San Diego)	New Mexico (Albuquerque)
FEE (*SUBJECT TO CHANGE)	$100 (intern) $250 (specialist)	$100 (intern)* $250 (specialist)*	$100 (intern)* $250 (specialist)*	$100 (intern)* $250 (specialist)	$100 (intern)* $250 (specialist)*
PLACE	FAIRMONT HOTEL	T.B.E.	T.B.E.	T.B.E.	T.B.E.

T.B.E. = To Be Established



Safeguarding Nuclear Materials This pamphlet is published by the Institute of Nuclear Materials Management (INMM), a private international, non-profit organization open to all professionals engaged in nuclear activities. The pamphlet is intended to provide an understanding of the measures employed in safeguarding peaceful use of nuclear energy. It focuses on facts and issues connected with domestic safeguards and international safeguards as embodied in the verification activities of the International Atomic Energy Agency. INMM would like to urge you, our current INMM Members to request copies of this nicely produced brochure and distribute them to the American public.



Simply request the quantity you would like to distribute by calling us at the INMM Headquarters:

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continued from page 3

Having the detectors, the amplifiers and pulse sorters, and the nuclear data, it was relatively easy to identify the gamma-ray lines associated with the isotopes in a sample; but measurements of the isotopic ratios were unreliable. The reason was that detectors were placed near the items in order to have a high counting rate. As a result, pulses overlapped with each other, so that the peak shapes were distorted and some pulses were removed from the peaks. Also, the gamma-rays of a given energy form a peak which is superimposed on a background of pulses due to partial detection of higher energy pulses. A combination of improvements in pulse amplifiers and improvements in computer analysis can now flag these problems and sometimes correct for such distortion.

Another important improvement was the development of "intrinsic" germanium detectors. In 1970, for example, when my friends and I had to take our lithium-drifted germanium detector somewhere, we would rent an extra seat on the airplane for the big thermosbottle needed to keep the detector continuously cooled by liquid nitrogen. This operation had to be carefully explained to the pilot, the crew and the passengers, as the package emitted an ominous vapor soon after the plane took-off. If these detectors ever warmed up, the lithium stopped compensating for the impurities, and the detector ceased detecting. Intrinsic germanium has so few impurities and dislocations, about one in ten to the twelfth, that there is no need for compensation by lithium; and the detector only needs cooling when in use. Incidentally, electrically operated cryostats have been designed and demonstrated to cool these detectors, so that it would not be necessary to obtain liquid nitrogen.

High resolution gamma-ray spectrometry for safeguards has taken advantage of many developments which took place for other purposes. It has reached a relatively advanced stage for safeguards applications due to the additional research and experimentation needed for this type of activity. As in other safeguards areas, the revolution in computer hardware and software contribute significantly to the present value of this NDA technique.

The evolution will continue as more experience is gained in the use of gamma-ray spectrometry and the users, for safeguards and for commercial nuclear purposes, become more demanding.

OPTIMAL ALLOCATION OF SAFEGUARDS INSPECTION RESOURCES FOR A NUCLEAR FUEL CYCLE

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ABSTRACT

In planning its safeguards inspections at peaceful nuclear facilities, the International Atomic Energy Agency must deploy its limited inspection resources according to some allocation procedure. In this paper I demonstrate a technique for optimally allocating such resources within a hypothetical nuclear fuel cycle.

I. INTRODUCTION

In planning and conducting its safeguards inspections, the International Atomic Energy Agency (IAEA) faces a resource allocation problem: how should it send its inspectors to nuclear facilities throughout the world to optimize the overall effectiveness of the inspections?[1] The allocation problem, which exists in theory for any resource level, is compounded by the persistent shortage of inspectors. Indeed, in 1984 (1982) IAEA inspectors only carried out about 71% (62%) of the total man-days of Planned Actual Routine Inspection Effort (PLARIE).[2,3] On the basis of operational considerations, the ARIE figures specified in negotiated facility attachments between States and the IAEA are adjusted to give the PLARIE figures. Such ARIE and therefore PLARIE figures are lower than the Maximum Routine Inspection Effort (MRIE) levels specified in the IAEA document INFCIRC/153,[4] which gives specifications for the application of IAEA safeguards at nuclear facilities in States party to the Nuclear Non-Proliferation Treaty (NPT).

There are actually two aspects of a complicated problem involved here.[5] The first is the acceptability of an incomplete fulfillment of PLARIE; this problem primarily reflects the underlying tension between the effectiveness of safeguards inspection activities and their intrusiveness or acceptability. With more resources, the IAEA could fulfill PLARIE completely. Since the provision of resources is basically a political problem that is dealt with annually by the Member States of the IAEA through the budget process, the incomplete fulfillment of PLARIE mirrors the consensus achieved by the States concerning the balance between the overall effectiveness and intrusiveness of safeguards. I shall not discuss this aspect in this article.

The second aspect is the allocation of the available resources at whatever overall fulfillment level of PLARIE is foreseen. This is the actual allocation problem faced by the IAEA Secretariat. I discuss a method for studying this aspect of the overall problem here. Given enough resources to fulfill 100% of PLARIE, the allocation aspect of the problem under study here disappears. There is the possibility, beyond the scope of this paper, of further allocation decisions through changes in the inspection activities that go into the ARIE determinations.

I illustrate a method developed by Sanborn, Fishbone, and Moresco[6] for studying this resource-allocation problem. The method involves several steps. First, the facilities to be safeguarded are specified; here, a hypothetical fuel cycle is considered (Section II). Second, three levels of safeguards effort--low, medium, and high--are defined numerically for each facility (Section III). Third, a quantified degree of safeguards value is associated with each safeguards level at each facility. Fourth, this value, a surrogate for safeguards effectiveness, is maximized over the whole fuel cycle subject to the constraint of limited annual inspection resources; thereby the optimum inspection level for each facility is selected (Section V). This optimality algorithm (Section IV) takes into account the dictum in Paragraph 6(c) of INFCIRC/153 that verification procedures should be concentrated on fuel-cycle facilities possessing the most sensitive nuclear materials.

There is an extensive history of safeguards studies whose authors' goals are to develop methods for allocating inspection resources in some optimal way.

Avenhaus and Gupta[7] presented estimates of inspection requirements for a complex fuel cycle, including optimal estimates based on probabilistic and game-theoretic considerations. Gupta et al.[8] showed how different intensities of verification lead to different inspection requirements.

Rometsch et al.[9] alluded to the problem of allocating inspection resources in any early discussion of an approach to verification based on the categorization of nuclear fuel by fuel cycle, fissile content, and amount of radioactivity.

Borgonovi and Glancy[10] and Glancy and Kull[11] established a "target attractiveness index" for nuclear material which could be used as a means for allocating rsources within a fuel cycle. They did not however, carry out such an allocation.

Indusi and Marcuse[12] used optimization techniques to determine the minimum cost of inspections consistent with a given limit on the uncertainty in the material unaccounted for. In a variation, Killinger[13] used the same technique to establish optimal sampling plans to minimize measurement variance at a mixed-oxide (MOX) fuel-fabrication plant given a limited budget for inspections.

Ikawa et al.[14] defined a "weighted significant quantity" (WSQ) as the number of SQs,[15] i.e., goal quantities of nuclear material, adjusted by a diversion factor, in a State's fuel cycle. This diversion factor quantifies the attractiveness of nuclear material to a potential divertor and encompasses, among other elements, fuel-cycle complexity. The authors used this WSQ method to determine attributes and variables sample sizes for several fuel cycles, one of which is similar to that studied here. Their basic result was that sample sizes (and thence, by implication, inspection effort) could be reduced substantially for low-enriched-uranium (LEU) bulk-handling facilities. The same conclusion has recently been drawn by de Montmollin, Higinbotham and Gupta[16] from another viewpoint.

In the context of the safeguards effectiveness assessment methodology,[17] Shea, Brach, and Ulvila[18] and Brown, Murphey, and Ulvila[19] proposed a detailed scheme for allocating inspection resources based on a cumulative "safeguards importance value" attached to the diversion paths covered by individual inspection activities. They showed generally how this value, in a ratio with the cumulative inspection-activity time, could be used to order the activities to be done at a single facility. Ulvila and Brown[20] carried out such a procedure for LWRs and Ulvila[21] did so for a MOX fuel-fabrication facility. The technique could presumably be used to allocate resources among several facilities as well.

Ellwein[22] propounded the theory for and Markin et al.[23] and Markin, Chambers, and Vaccaro[24] performed an idealized optimization to allocate inspection resources within a facility. Their technique was to maximize the overall probability that a collection of inspection activities leads to anomaly detection given a constraint on overall resources available to conduct the activities. They suggested extension of the technique to allocation among facilities. Vaccaro[25] later used these techniques to duplicate the calculations of an earlier version of this paper.

The method discussed here for studying resource-allocation problems was formulated for and presented to the IAEA in 1980 under the auspices of the U.S. Program for Technical Assistance to IAEA Safeguards (POTAS). This paper was motivated by recent use of the model for the IAEA's Standing Advisory Group on Safeguards Implementation (SAGSI)[26] and for the IAEA Consultants' Meeting on the Application of Safeguards to Multiple Facility Fuel Cycles.[27] At the Consultants' Meeting, fuel-cycle considerations of this and other allocation models were emphasized. Nevertheless, the model is neither in routine use by the IAEA nor under further development for it, and nothing in this paper necessarily reflects the views or has the endorsement of the IAEA. Indeed, the Consultants found that "None of the..." resource-allocation "...algorithms described appear to the group to be very promising as a means of allocating scarce resources."[28] In this paper I present the method to a wider audience, since it has potential application elsewhere.

II. HYPOTHETICAL NUCLEAR FUEL CYCLE

A hypothetical fuel cycle was chosen to illustrate the method. This fuel cycle is more advanced than any existing one, but it serves well as the setting for a safeguards resource-allocation problem by including several facilities with separated plutonium. With one exception, the individual plants are characteristic of existing facilities. Figure 1 illustrates the fuel cycle schematically and provides information regarding nuclear-material flows.

The fuel cycle accepts unenriched uranium hexafluoride and includes one enrichment plant, one fabrication plant for LEU fuel assemblies, ten pressurized-water reactors (PWRs) using LEU fuel, one spent-fuel reprocessing plant, one fabrication plant for MOX fuel assemblies, and four reactors using MOX fuel. Almost all of the plutonium produced in the ten LEU-fueled PWRs is recycled once through the four MOX-fueled PWRs. Some plutonium from the reprocessing plant is placed in a sealed storage facility--not considered here--and some recycled uranium from the reprocessing plant is available for enrichment. The fuel cycle is indigenous in that no imports and exports are included. It is "balanced" in that almost all plutonium produced in the LEU-fueled PWRs is reused in MOX-fueled PWRs; the spent-fuel assemblies from the latter are not further reprocessed. Steady-state flow conditions pertain throughout. Except for the enrichment plant, the bulk facilities are all assumed to have a nuclear-material product yield of 98% of the facility input.

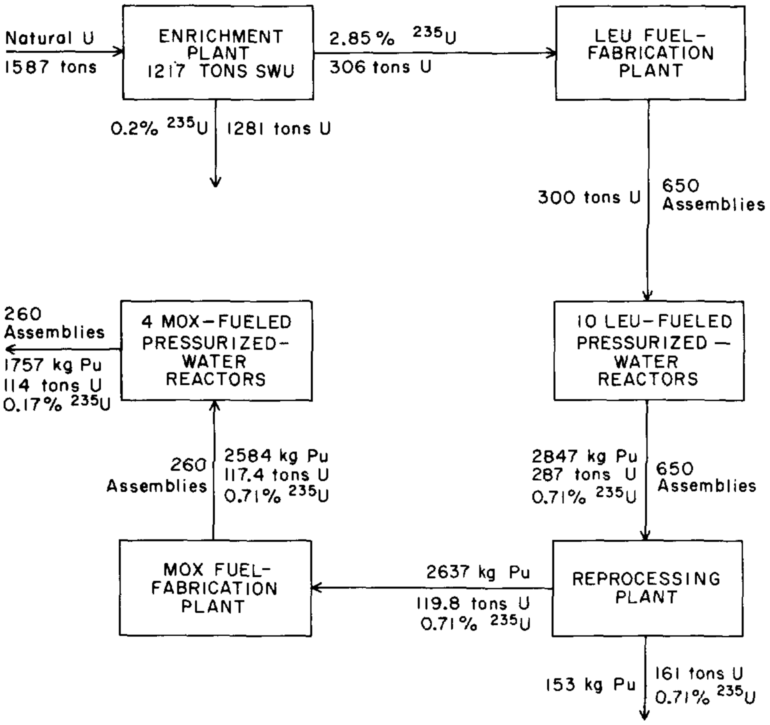

Figure 1. Annual fuel flows in the hypothetical nuclear fuel cycle.

Table 1

Fuel Assembly Content by Mass

Material	Content in LEU-Fueled Reactor (kg)		Content in MOX-Fueled Reactor (kg)	
	Fresh Fuel	Spent Fuel[b]	Fresh Fuel[b]	Spent Fuel[c]
U	461.54	442.27	451.59	439.88
^{235}U	13.15	3.14	3.21	0.77
^{238}U	448.39	439.13	448.38	439.11
Pu[a]	0	4.38	9.94	6.76
Burnup	0	14.89[d]	0	14.89[d]

Notes for Table 1

[a] For simplicity, the listings for Pu encompass all transuranics otherwise unlisted.

[b] By assumption, the LEU spent fuel and MOX fresh fuel both contain U at natural enrichment.

[c] Both the original ^{235}U and original Pu in the MOX fuel are assumed to be depleted to the same degree as is the original ^{235}U in the LEU fuel, i.e., to 0.239 of their original amounts. Some of the Pu produced in both types of fuel is burned in situ as well.

[d] Based on the energy consumed by an 1100 megawatt (electric) reactor with a thermal efficiency of 33%, a capacity factor of 75%, and an annual flow of 65 assemblies. The number 14.89 kg of burnup is equivalent to 30,400 megawatt-days per metric ton of original heavy metal, the conventional unit.

The enrichment plant is a small version of the now defunct Portsmouth Gas-Centrifuge Enrichment Plant.[29] The hypothetical plant produces 1217 metric tons of separative work annually and yields a product enrichment of 2.85% and a tails enrichment of 0.2%. The annual plant flows significantly exceed its process inventory and it maintains a noncascade inventory of 28% of its annual flow (as measured in mass of ^{235}U).

One LEU fabrication plant takes all of the enriched uranium and processes it into PWR assemblies. The plant maintains an inventory of 50% of its annual production of 306 metric tons of uranium in 650 fresh fuel assemblies.

Ten LEU-fueled PWRs in the fuel cycle each have a capacity of 1100 megawatts (electric). They have a thermal efficiency of 33% and a capacity factor of 75%. Their cores contain 195 assemblies with an average residence time of three years, and they keep one year's worth of fresh fuel and three year's worth of spent fuel. I assume that the fuel burnup is such that the spent fuel contains uranium at natural enrichment and plutonium with a mass equal to 0.95% of the mass of the original uranium. Table 1 describes the quantitative details for each assembly.

The reprocessing plant has slightly more capacity than the existing Tokai Reprocessing Facility in Japan.[30] It accepts 650 spent-fuel assemblies annually from the ten LEU-fueled PWRs and yields 2790 kg of plutonium and 281 tons of uranium. Of this total, 94.5% of the plutonium and 43% of the uranium go to the MOX fuel-fabrication plant. The reprocessing plant's inventory is 50% of its annual flow as spent fuel and 25% as plutonium product. I assume that conversion of plutonium from nitrate solution to oxide powder occurs in the plant.

One MOX fuel-fabrication plant larger than any now existing[31] but smaller than one once contemplated[32] is required to produce the fuel assemblies for the MOX-fueled PWRs. The fabrication plant maintains an inventory of 50% of its total annual flow of nuclear material. The annual flow of plutonium is 2637 kg; 260 fuel assemblies are produced.

Finally, four PWRs burn the MOX fuel assemblies. These PWRs are identical to the aforementioned LEU-fueled PWRs. Only the fuel composition differs as described in detail in Table 1.

III. SAFEGUARDS LEVELS

Basic to the problem of allocating resources is the notion that differing levels of safeguards inspection effort imply differing levels of safeguards effectiveness. If such levels exist for each facility in the hypothetical fuel cycle, then it is plausible that the effectiveness of safeguards over the whole fuel cycle could be enhanced by imposing relatively more intense safeguards at some types of facilities and relatively less intense safeguards elsewhere, i.e., graded safeguards. Such an allocation procedure is explicitly mentioned in Paragraph 6 of INFCIRC/153.

I consider three safeguards levels for each facility type. Ideally, these levels would depend on careful consideration of actual inspection activities carried out at each facility.[27] I consider here one level close to that negotiated for routine inspections, one identical to the negotiated maximum, and one based on an arbitrary formula. This choice makes the problem I study here numerically unrealistic but nevertheless allows the method to be demonstrated. More levels, leading to a limiting case of continuous variation of effort, would go beyond the programming limitations of the model, which is no longer under development.

Table 2 summarizes the three safeguards levels for each facility in terms of the number of inspector man-days required to implement each. Also listed in Table 2 are the amounts of nuclear material at each facility. Although the levels in this illustration are not related specifically to inspection goal attainment, even the lowest level provides enough effort to satisfy timeliness requirements--albeit barely for level 1.

For each of the facility types, level 3 is the MRIE level specified by Paragraph 80 of INFCIRC/153. Understand clearly that I am using MRIE values for level 3 not because I or any organization necessarily recommend them, but merely because they are published, well-defined values.

Level 2 for each facility type except the MOX-fueled reactor is the ARIE value as described in some published report or an approximation thereto based on extrapolations or interpolation. A numerically realistic approach to the actual problem would likely employ ARIE values as the most intense safeguards level.[27] For the MOX-fueled reactors, the ARIE value is derived from the calculation described next.

With two exceptions, level 1 for each facility type, the lowest routine inspection effort (LRIE), is derived mathematically from the other two levels. The relation is that the ARIE value is the geometric mean of the MRIE and LRIE values. For MOX-fueled reactors, the LRIE value is chosen to conform realistically with a one-month plutonium timeliness requirement[36]; the ARIE figure is then derived from the LRIE and MRIE figures for this type of facility. For LEU-fuelled reactors, the LRIE figure is chosen to conform with a three-month timeliness requirement[15] yet differ from the ARIE value.

Table 2 also lists the amounts of nuclear materials at each type of facility, defined to be the inventory plus the annual flow. To avoid

Table 2

Facility Nuclear Materials
and Inspection Levels

Facility	Amount of Nuclear Material (SQ)[a]				Inspection Levels (man-days)		
	LEU[b]	Pu (Spent Fuel)	Pu (Separated)	Combined[c]	Level 3 (MRIE)[d]	Level 2 (ARIE)[e]	Level 1 (LRIE)[f]
Enrichment	193			193	225	144[g]	92
LEU Fuel Fabrication	174			174	200	82[h]	34
LEU-Fueled Reactors(10)	44	196[i]		207	50	10[j]	5[o]
Reprocessing	49	178	442	501	1609	704[k]	308
MOX Fuel Fabrication	17		495	496	1544	·287[l]	53
MOX-Fueled Reactors(4)	13	369[i]	162	277	50	31[m]	19[n]
Fuel Cycle					4278	1441	613

Notes for Table 2

[a] Number of significant quantities of nuclear material at each facility in its inventory plus annual flow. One SQ of Pu is 8 kg; one of ^{235}U is 75 kg for LEU, natural U, or depleted U.(15)

[b] Where appropriate, includes LEU in spent fuel.

[c] The combination of nuclear-material weight and relative safeguards relevance (see Table 3) which, if multiplied by the relevance of the most relevant material, gives the correct summation in formula (4) of Section IV.

[d] MRIE, maximum routine inspection effort, is calculated for each facility from a formula that depends on the larger of nuclear-material flow and inventory for bulk-handling facilities, and is 50 man-days per year for reactors (see Paragraph 80 of INFCIRC/153).

[e] ARIE, actual routine inspection effort, the negotiated figure generally based on an estimate of likely inspection activities needed to achieve the IAEA's inspection goals. The figures used here are with one exception published values or estimates of the times required for such a set of activities.

[f] LRIE, lowest routine inspection effort, a number defined in the present article with two exceptions by the arbitrary formula $\text{LRIE} = (\text{ARIE})^2/\text{MRIE}$.

[g] Extrapolated from a figure in Reference 33.

[h] Interpolated from figures in Reference 34; compare reference 2.

[i] Includes Pu in the irradiated reactor-core assemblies.

[j] Taken from Reference 2 for single-reactor stations; the smaller figure in the bimodal distribution is used.

[k] Extrapolated from a figure in Reference 35.

[l] Extrapolated from a figure in Reference 31; compare reference 2.

[m] Calculated from LRIE and MRIE using the formula in footnote f.

[n] Chosen to be 19 as the minimum number capable of achieving a one-month timeliness requirement(36) for plutonium: eleven 1 man-day interim inspections; and one open-core, 8 man-day physical inventory verification. Compare this figure with the 5 man-day LRIE figure for LEU-fueled reactors inspected four times per year. See also reference 37.

[o] Chosen to be 5 as the minimum number capable of achieving a three-month timeliness for irradiated fuel with a 2 man-day physical inventory verification.

double counting, the flow is arbitrarily counted as the most safeguards-relevant nuclear-material stratum, i.e., the one whose material has the shortest conversion time.[15]

Necessary later is a quantitative measure of relative nuclear-material safeguards relevance. I use for this the inverse of the conversion time for each material relative to the value for metallic plutonium or highly enriched uranium; the values appear in Table 3. This measure takes into account the different physical, chemical, and radiological forms of the materials. It has also recently been used by de Montmollin, Higinbotham, and Gupta[16] for a quite different calculation, and something similar has been used by the IAEA. (A different measure, nuclear-material importance weight, has been used by the IAEA in the context of the safeguards effectiveness assessment methodology.[17,38]) Numerically, the definition in Table 3 also has the effect of furthering the intent of Paragraph 6(c) of INFCIRC/153, which provides for "concentration of verification procedures on those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made, and minimization of verification procedures in respect of other nuclear material, on condition that this does not hamper the Agency in applying safeguards under the Agreement." This measure also conveys information about relative timeliness goals[15] and quantities that might depend on them.

IV. MATHEMATICAL FORMULATION OF THE RESOURCE-ALLOCATION PROBLEM

A linear program is a mathematical formulation of the problem of maximizing a linear function of several variables subject to linear constraints linking the variables.[39] A typical application is to maximize the profit of an enterprise capable of producing various products but given constraints on the raw materials: What is the profit-maximizing product mix? The mathematical variables in the problem are the numbers of each type of product; both the profit function and the constraints are linear functions of the variables. The extension to mixed-integer programming involves the restriction to integer values for some of the variables. Techniques for solving such problems are well known.

One key point in interpreting results of typical mathematical-programming problems is that the objective function is a well-understood, deterministic function of the variables of the problem and is usually mathematically identical to the actual objective, say profit. In the application to safeguards inspections considered here, the objective function is a deterministic function of the variables of the problem but is only subjectively related to the actual goal, safeguards effectiveness. The numerical value of the objective function is what I have referred to in the Introduction as the value of safeguards over the whole fuel cycle.

The objective function in the problem here is the amount of nuclear material within the fuel cycle, weighted by (1) its relative safeguards relevance, (2) the level at which it is safeguarded, and (3) the nature of the facility at which it is located; these weights are quantified in coefficients a_{ij}. (Ulvila[38], in a different context, uses the square root of the amount of nuclear material at risk as an index of safeguards value.) The variables in the problem, x_{ij}, are the numbers of facilities of each type i at each safeguards level j, and the one constraint value considered here is the total available annual inspector effort C, expressed in man-days. Mathematically, the problem is to

$$\text{Maximize} \quad \sum_{i=1}^{N} \sum_{j=1}^{3} a_{ij} x_{ij} \qquad (1)$$

$$\text{subject to} \quad \sum_{i=1}^{N} \sum_{j=1}^{3} b_{ij} x_{ij} < C \qquad (2)$$

$$\text{and, for each } i, \quad \sum_{j=1}^{N} x_{ij} = n_i \qquad (3)$$

The coefficients b_{ij} are the safeguards inspection resource demands given in Table 2 for facility type i at level j, and the constraint (3) is a technical one ensuring that each facility is safeguarded at one of the three levels; n_i is the number of facilities of type i, and N is the number of facility types.

The coefficients a_{ij} determine the objective function to be maximized; they are defined as follows:

$$a_{ij} = \sum_{k} [m_{ik} (t_{\text{Pu,HEU Metal}}/t_k)] f_i s_{ij} \qquad (4)$$

where, for facility type i, m_{ik} is the amount of nuclear material of type k in significant quantities; $(t_{\text{Pu,HEU Metal}}/t_k)$ is the relative safeguards relevance of nuclear material k, (equivalent to the inverse of its conversion time relative to that for Pu or HEU metal); f_i is the relative safeguards value for facility type i; and s_{ij} is the relative safeguards value for level j at facility type i. The factors f_i and s_{ij} must be assigned subjectively, thereby adding to the subjective nature of the problem. (For the calculations reported in Section V, $s_{i1}=1$, $s_{i2}=2$, and $s_{i3}=3$ for all i.) For all of these factors, higher values imply greater safeguards importance.

Maximizing the objective function (4) is therefore equivalent to maximizing the sum over all facilities of the following product: the value of the safeguards level at each facility times the amount and the safeguards relevance

Table 3

Nuclear-Material Conversion Time and Relative Safeguards Relevance

Material	Conversion Time[a] (weeks)	Relative Safeguards Relevance[b]
LEU	52	0.019
Pu or HEU[c] in Spent Fuel	13	0.077
Compounds of Separated Pu or HEU	4	0.25
Pu or HEU Metal	1	1.0

Notes for Table 3

[a] From references 15 and 36, with the longer times chosen here for compounds

[b] Inverse of the conversion time relative to that for Pu or HEU metal

[c] Highly enriched uranium

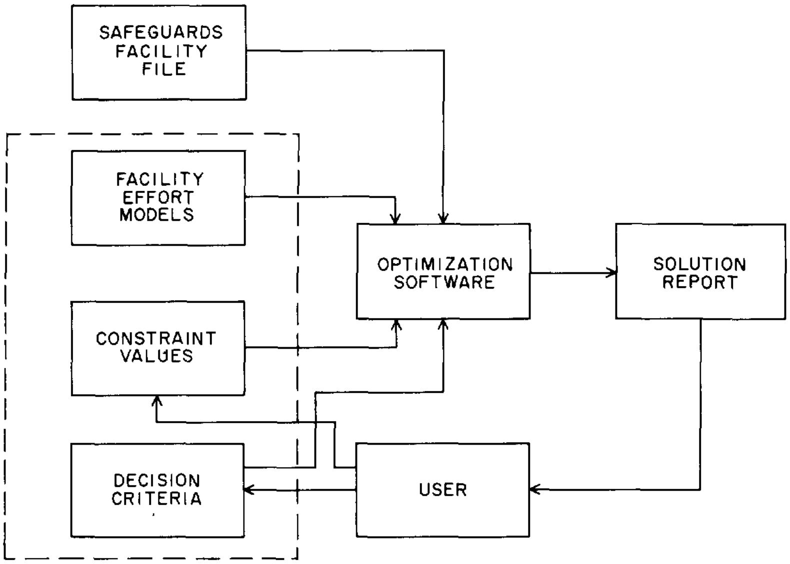

Figure 2. Computer organization of the resource-allocation program. The facility file, optimization software, and the three elements together within the dashed box constitute three separate computer files (figure from reference 6).

of the types of material there. This is tantamount to embodying the notion of graded safeguards within the objective function, i.e., to saying that safeguards activities are more effective if the more safeguards-relevant nuclear materials at the more sensitive facilities receive resources first--within the resource constraints. This agrees with several of the precepts of Paragraph 81 of INFCIRC/153.

If the amount of nuclear material is not to be a distinguishing factor in computing a_{ij}, m_{ik} is set to unity and the k summation is suppressed in formula (4). Then only the nature and number of facilities and the nature of their materials matter, not the facility flows and inventories.

Generally, the variables x_{ij} take on nonintegral values in the solution of a linear program. If n_i is large, rounding off such x_{ij} to integral values is acceptable. If n_i is small, i.e., if there is only one facility or a few facilities of a given type, or if one insists that all facilities of a given type undergo safeguards at the same level, then only one of the three x_{ij} would be nonzero and would equal n_i. This restriction of possible solutions represents an integer program. (Actually, the variables are redefined for computer purposes to be x_{ij}/n_i and have the possible values zero and one.) Combining both possibilities (for different facility types) yields a mixed-integer program, which is what is used for the safeguards resource-allocation computer model.

Several mathematical features of the complete computer model[6] are not exploited in this paper. First and foremost, there can be more than one constraint. Here I only use inspection effort; other possible limiting factors include travel time and equipment. Constraints involving each could be imposed simultaneously were the data available. Second, the constraint coefficient b_{ij} can either be determined for a particular plant size, as in Table 2, or be defined as a function of facility size if the model is to be used for studying facilities of different size. Possible functions already part of the computer model are constants, linear functions of size, and functions asymptotically linear (with different slopes) at small and large size.

A standard set of computer algorithms[40] is used to solve the problem represented by the mathematical relations (1), (2), (3), and (4). Figure 2 depicts the computer organization and how users interact with the files.

V. CALCULATIONS

V.A. Sample Exercises

To illustrate the use of the computer algorithm, I have applied the optimization technique for inspection allocation to the facilities of the hypothetical fuel cycle in two sample exercises.

In the first, I used as distinguishing parameters only the safeguards levels described in Table 2, and, with one exception, the relevance factors listed in Table 3. The one exception is that the nuclear material in the enrichment plant was assigned the relative safeguards relevance of HEU instead of that of LEU. Justification for such an emphasis would be that the enrichment plant is potentially capable of producing HEU by cascade-piping alterations.

In the second sample exercise, the importance of the reprocessing plant was enhanced by a factor of ten and that of the LEU- and MOX-fueled reactors decreased by a factor of ten, both by adjustments in the factor f_i in equation (4). Justification for the first change is that the reprocessing plant is the facility where plutonium in the fuel cycle first becomes accurately measurable. Justification for the second change is that the containment of nuclear material within fuel assemblies (possibly identifiable) makes that material more difficult to divert without detection than material in a bulk-handling facility. (This second change could alternatively be taken into account by lowering the inspection-effort values for reactors.) The material in the enrichment plant was assigned the relative safeguards relevance of LEU in the second exercise.

Figures 3 and 4 respectively depict the optimal level structure of the fuel-cycle safeguards as a function of the available inspector effort for the two sample exercises. The range of values for inspector effort varies from 613 man-days, for which all facilities are safeguarded at level 1, to 4278 man-days, for which all facilities are safeguarded at level 3. For values lower than 613 man-days, the problem is mathematically infeasible; for values higher than 4278 man-days, nothing is gained given the inspection levels defined. At the intermediate value of 1441 man-days, each facility could be safeguarded at level 2 were the optimization procedure to so allocate the resources; it does not in the two sample exercises. Separate optimization calculations were done for each value of the abscissa listed in the figures but for no others; these values represent the constant C in constraint (2). Calculations at other intermediate values could give more structure to the figures, but the general features would not change. Finally, the numbers for the LEU-fueled reactors give the split among levels allowable for them if there is a split.

The curve at the bottom of Figure 3 gives the unused man-days (the "slack value" in linear-programming language) at each level of effort. There are unallocated man-days because the model, as currently developed, involves discrete--not continuous--levels of safeguards activities. The large slack values in Figure 3 reflect the unrealistically large gap between

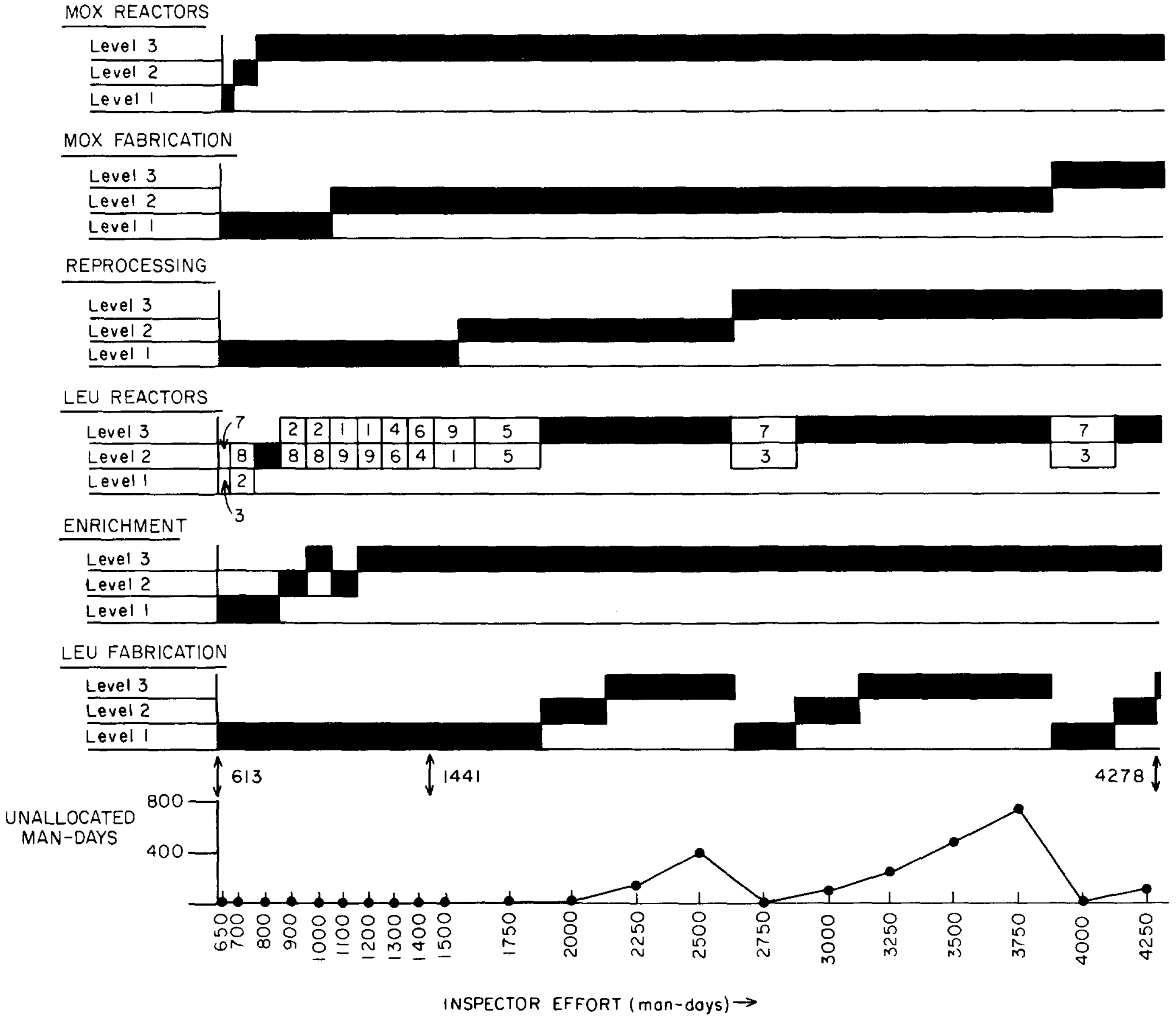

Figure 3. Facility safeguards level structure as a function of available inspector effort for a situation where the nuclear material at the enrichment plant is assumed to have the relative safeguards relevance of HEU. For the LEU-fueled reactors, the numbers give the split among levels. The curve at the bottom gives for each overall effort value the "leftover" inspector effort that cannot be usefully allocated by the model as currently developed because the levels of safeguards activities at the facility types are discrete--not continuous--variables. In particular, the large unallocated values culminating at the overall effort level of 3750 man-days occur because of the huge jump in effort required to change from level 2 to level 3 safeguards at the MOX fabrication plant. The abscissa at the bottom applies to all sections of the graph; the safeguards level structure was computed only for the abscissa values listed. The values of 613, 1441, and 4278 man-days are those respectively needed for level 1, 2, or 3 safeguards at all facilities. Level 2 safeguards are not chosen by the optimization procedure for all facilities at 1441 man-days.

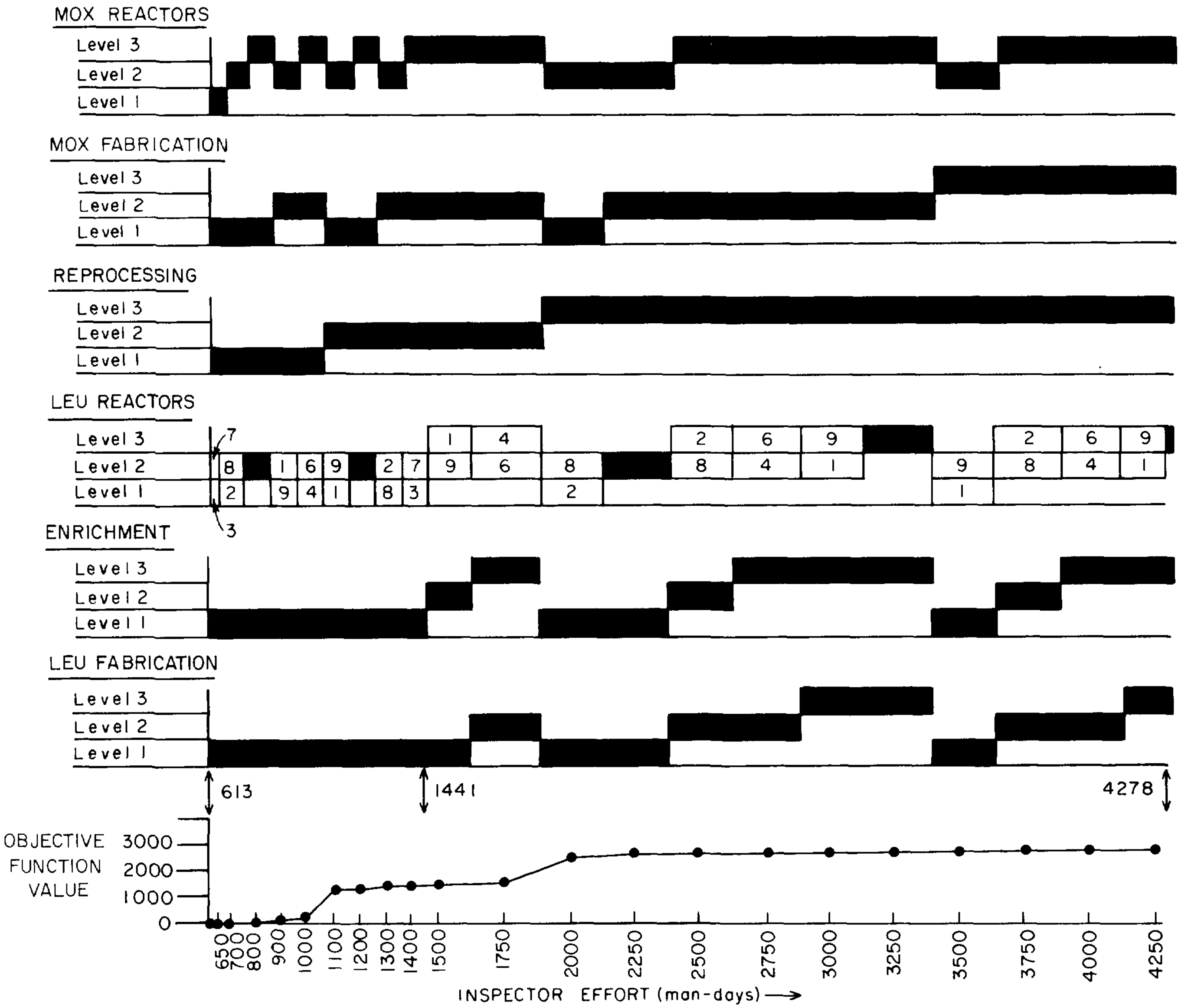

Figure 4. Facility safeguards level structure as a function of available inspector effort for a situation where the importance of the reprocessing plant is enhanced and that of both kinds of reactors is decreased. Only at the effort level of 3250 man-days is the effort not entirely allocated; at that value, 229 man-days are unallocated. Also plotted is the value of the strictly nondecreasing objective function, the surrogate for safeguards effectiveness; the two large increases in this function occur when the safeguards level at the reprocessing plant jumps.

Table 4

Marginal Value[a] of Facility Safeguards Level Changes

Facility	Marginal Value	
	Level 1 to Level 2	Level 2 to Level 3
Enrichment	$\frac{3.67}{144-92} = 0.07$ (1.14)[b]	$\frac{3.67}{225-144} = 0.05$ (0.79)[b]
LEU Fuel Fabrication	$\frac{3.31}{82-34} = 0.07$	$\frac{3.31}{200-82} = 0.03$
LEU-Fueled Reactors	$\frac{15.94}{10-5} = 3.19$ (0.32)[c]	$\frac{15.94}{50-10} = 0.40$ (0.04)[c]
Reprocessing	$\frac{125.25}{704-308} = 0.32$ (3.2)[d]	$\frac{161.84}{1609-704} = 0.14$ (1.4)[d]
MOX Fuel Fabrication	$\frac{124.00}{287-53} = 0.53$	$\frac{124.00}{1544-287} = 0.10$
MOX-Fueled Reactors	$\frac{69.25}{31-19} = 5.77$ (0.58)[c]	$\frac{69.25}{50-31} = 3.64$ (0.36)[c]

Notes for Table 4

[a] Defined as the ratio between the objective-function-coefficient difference and the inspection-effort difference for the facility for changes between the given levels. The units are unimportant.

[b] Values in parentheses for the enrichment plant are for the case where the relative safeguards relevance of HEU is used.

[c] Values in parentheses for the reactors are for the case where the containment provided by fuel assemblies is deemed to reduce the reactors' importance by a factor of ten.

[d] Values in parentheses for the reprocessing plant are for the case where the crucial plutonium measurements there are deemed to increase the plant's importance by a factor of ten.

the effort required for level 3 and level 2 safeguards. Nevertheless, the model could be further developed or any actual user would decide to allocate these "leftover" man-days (a) to the facility type at which they are most needed in terms of increasing the value of the objective function (see Section IV.B), (b) randomly to several facility types, (c) deterministically by increasing the number of safeguards levels, or (d) in some other way. One sense in which unallocated man-days might be deliberately provided for would be to allow for contingencies such as ad hoc inspections; however, the number would then not be allowed to vary as erratically as in Figure 3.

In the example illustrated in Figure 3, the MOX-fueled reactors attain level 3 first (i.e., for the lowest inspector-effort values), followed soon by the enrichment plant, all of whose material is given the relevance of HEU in this exercise. The MOX fabrication plant jumps to level 2 relatively early and to level 3 much later. The reprocessing plant follows this behavior but with a more even distribution of levels. As inspector effort allows, the LEU-fueled reactors are split at higher levels relatively early. The LEU fabrication plant is the least attractive facility to safeguard, staying at level 1 the longest and moving back from high to low levels as other facilities, requiring inspection resources, move up. The jump down from level 3 to level 1 for the LEU fabrication plant and the decline in unused inspector effort between 2500 and 2750 man-days are both required to support the concomitant jump from level 2 to level 3 for the reprocessing plant. Other up-and-down behavior can be similarly explained.

This superficially peculiar up-and-down behavior (typical of linear-programming applications) occurs because the model always operates so as to maximize the objective function--enhance safeguards effectiveness--over the entire fuel cycle. As long as resource constraints prevent application of the inspection resources at a more sensitive facility, the resources will be applied at a less sensitive facility. But when the resources increase sufficiently, the model will apply them to the more sensitive facility--even at the expense of the less sensitive one-- and the objective function will increase in value. Furthermore, the dependence of the level structure on effort available is nothing that would ever be experienced in practice: there is only a single level of effort available. The dependence only occurs in studying the problem.

An alternate algorithm, according to which levels at all facility types must only increase monotonically and all facilities must be at level 2 before any passes to level 3, is at variance with the notion of graded safeguards, which the model under study here embodies.

Vaccaro[25] studied a slightly different example from an earlier version of this paper and relaxed the constraint that all facilities must at least be safeguarded at level 1. Below the resource level of about 1000 man-days, his solution permits a higher objective-function value at each effort value by not providing for any inspections at all at some facilities and allocating the available effort to others with a relatively high objective-function value. Interpreted strictly, such an allocation is probably not politically acceptable. However, interpreted less strictly, this result provides support to the randomization-over-facilities approach under discussion elsewhere[28] in the sense of allocating effort to sensitive facilities without completely eliminating inspections elsewhere.

A major difference in the Figure 4 situation compared to the Figure 3 situation is the early attainment of level 2 and then level 3 safeguards by the reprocessing plant. The enrichment plant and the LEU fabrication both remain at the lowest levels the longest and, in contrast to the Figure 3 situation, are at the same level at almost all effort values. In this exercise the nuclear material at both plants is accorded the relative safeguards relevance of LEU.

V.B. Analysis

Figures 3 and 4 depict safeguards inspection-effort allocation for the model fuel cycle under different assumptions. The level structure of the facility safeguards as a function of effort depends both on the relative importance of safeguards at each facility and on the effort required for implementing safeguards at each.

One aid to understanding the allocation is an analysis (motivated in this context by ideas of G. Naegele) of the ratio of the difference in the objective-function values between levels to the difference in the inspection resource values.[27] This ratio is listed in Table 4 for the parameter values in Tables 2 and 3 as well as for the assumptions used in the Figure 3 and 4 sample allocation exercises. This ratio (called the "marginal value") can generally be used to predict the level structure in the following sense: given the structure at any particular effort value, the facility and level change with the highest applicable ratio will occur provided that the next increment in effort is sufficient. For example, in Figure 3 the initial behavior is that MOX-fueled reactors move to level 2 (for which the ratio is 5.77) and level 3 (3.64) first, LEU-fueled reactors then move in toto to level 2 (3.19), the enrichment plant then moves to levels 2 (1.14) and 3 (0.79), and the MOX fabrication plant moves to level 2 (0.53). This is precisely the order predicted on the basis of the Table 4 ratios given parenthetically. Note that the enrichment plant returns to level 2 when the MOX fabrication plant moves from level 1 to level 2. This occurs because the objective function increases in value; in this case, the change suggested by the marginal values is outweighed by the change suggested by the "integral" value, which absolutely controls the structure.

Curiously, the value of the objective function (1), the subjectively weighted amount of material under safeguards, is not itself important as a result; its shape (see Fig. 4) is.[25] This is so both because the objective function is a subjective surrogate for safeguards effectiveness and because there is no absolute scale for the factors that enter into its definition through equation (4). Of primary importance is the safeguards level for each facility type, determined through objective-function maximization. This differs from the traditional linear-programming application, where the objective function itself gives the profit expected for the optimal product mix (q.v. the first paragraph of Section IV).

VI. DISCUSSION

Serious management use of the inspection-effort allocation procedure described here would require study of the allocation problem under a variety of assumptions and for the range of important effort values. Indeed, as I have already mentioned, quantities other than inspector effort might be constrained, necessitating studies dependent on more than one type of demand. This would both complicate the analysis as well as add more realism.

Aside from the inherent limitations of the allocation model, the key deficiencies of the calculations summarized here with respect to those that the IAEA would use are, first, the reliance on unrealistic facility safeguards levels as opposed to levels derived from an analysis of actual inspection activities[27] and, second, the use of a hypothetical fuel cycle. Both could be corrected for actual IAEA applications at the State or world level. Indeed, reference 6 contains a sample analysis of safeguards at all EURATOM facilities.

VII. ACKNOWLEDGMENTS

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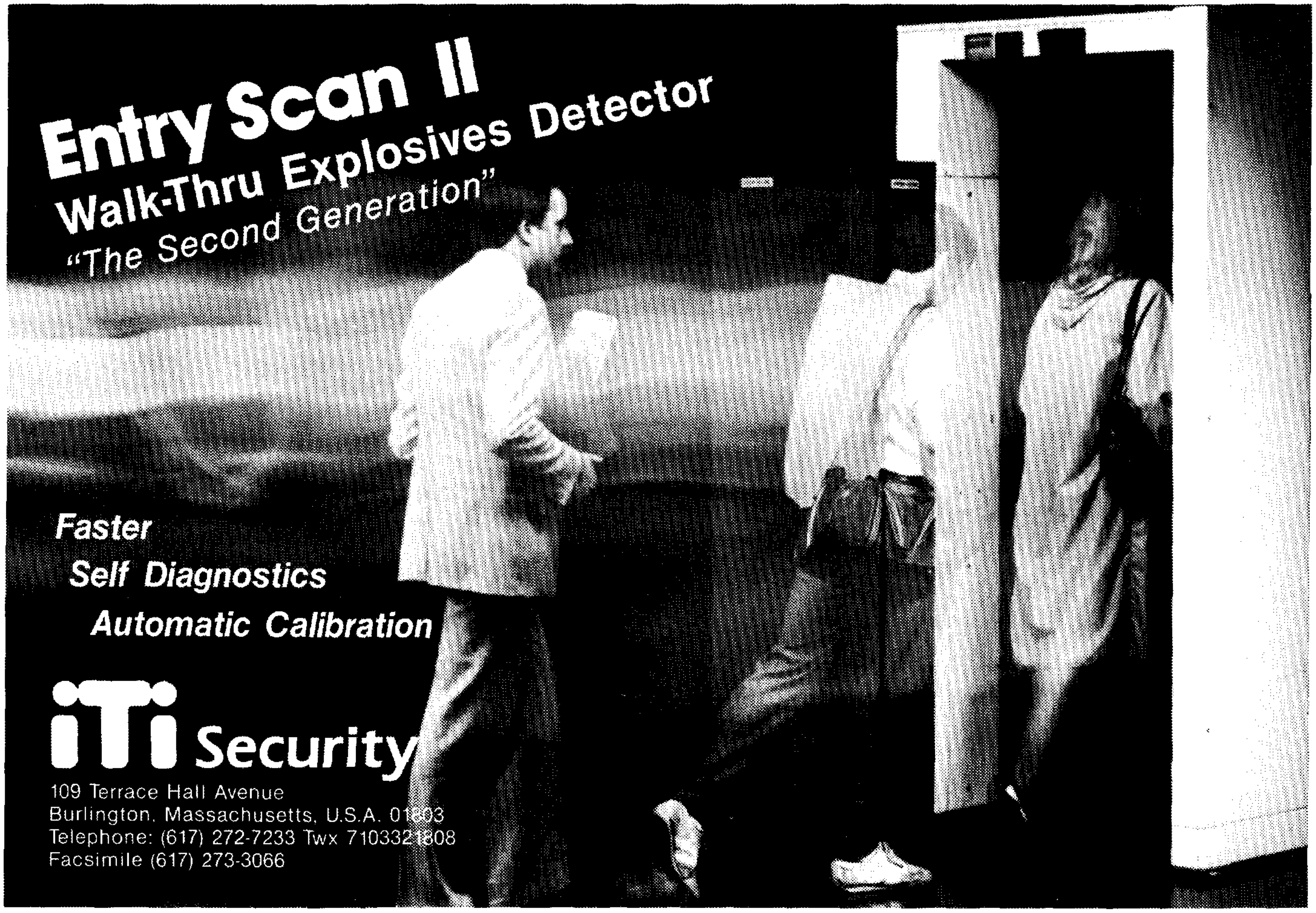

U-235 ENRICHMENT DETERMINATION VIA GAMMA SPECTROSCOPY—IMPROVED CALIBRATION AND "UNKNOWN" SAMPLE ASSAY

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ABSTRACT

An improved method of calibrating NDA gamma spectroscopic instrumentation for U-235 enrichment determination is presented. The calibration utilizes a chi-squared minimization method to fit two coefficients to the data. Sources of uncertainty in the initial data are used to "weight" the fit; uncertainties are computed for the two fitting coefficients. The calibration procedure and calculation of "unknown" enrichments is demonstrated. Only simple counting instrumentation is needed; calculations can be readily handled by small computers. An example calculation and program listings are included.

INTRODUCTION

Determination of U-235 enrichment by means of gamma spectroscopy is a commonly used technique for safeguards measurements.[1] Assays of this type generally involve measurement of the count rate due to the 185.7 keV gamma line by use of an NaI(T1) detector which views an "infinitely thick" sample. In most cases, the detector/sample geometry is fixed, and the detector is collimated so that it views only a well-defined area of the sample. Control of the measurement geometry helps to ensure that extraneous radiation due to nearby samples, etc., does not affect the assay data. Analysis techniques for gamma spectroscopic data range from extremely simple (for use with health physics instrumentation) to sophisticated (computer-based spectroscopy with peak fitting). Perhaps the most commonly used instumentation is that shown in figure 1: gamma rays in the 185 keV region are counted along with those in a background region immediately above (in energy) the 185 keV peak via two single channel analyzers, two scalers, and an adjustable time base generator. Briefly, gamma radiation from a sample is converted to electrical pulses in the NaI detector. These pulses are amplified and sorted into "peak" or "background" regions by single channel analyzers (SCA) or discarded. The "peak" region generally encompasses all detected gamma rays arising from interactions of the 185 keV gamma in the NaI scintillator. The background region located above the peak region to avoid counting Compton interactions due to the 185 keV gamma, may be any convenient size. Typical counting regions are shown in figure 2.

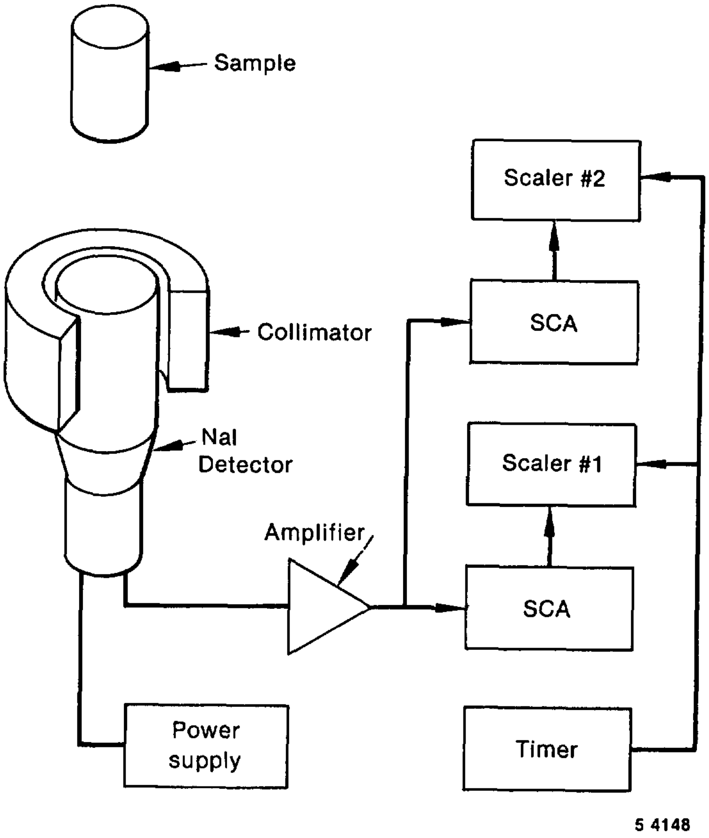

Figure 1. Gamma spectroscopy instrumentation for determining U-235 enrichment.

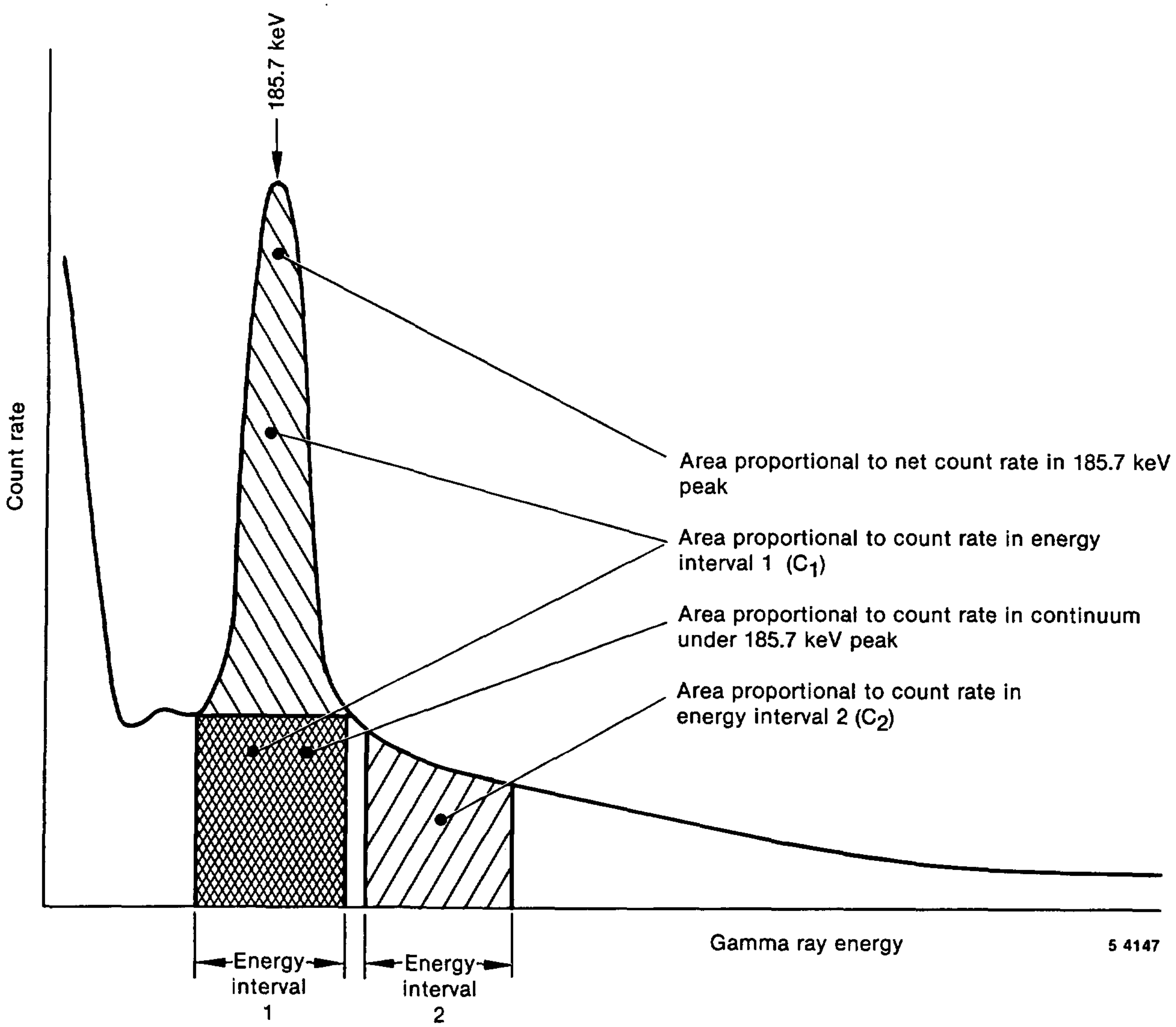

Figure 2. Multiple single channel analyzer approach for determining U-235 enrichment.

CALIBRATION TECHNIQUES

Several different methods of relating the U-235 enrichment to the peak and background region count rates have been developed. One of the most successful is that described by Kull and Ginaven:[2] The sample enrichment, E, is given by:

$$E = pC_1 - qC_2$$

where C_1 and C_2 are the count rates due the peak and background regions, respectively, and p, q are parameters to be determined from measurements of samples whose enrichments are known. Reference 2 gives a method of computing p and q using two samples. This simple calibration has been used extensively[3,4] for safeguards measurements.

A more rigorous treatment of SCA count rate data can be carried out using X^2 minimization methods.[5] The chi-squared treatment permits data from a larger number of measurements to be used in calibrating the instrumentation. It also yields estimates of the uncertainties associated with coefficients p and q, which are necessary to correctly estimate the enrichment uncertainties for "unknown" samples. The calculations are derived below:

Starting with $E = pC_1 - qC_2$, we minimize X^2, where:

$$X^2 = \sum_{i=1}^{N} (E_i - (pC_{1i} - qC_{2i}))^2 W_i$$

Note that "N" different calibration measurements are used each of which consists of count rates C_{1i}, C_{2i} for calibration samples of enrichment E_i.

The weighting factors, W_i, are unique for each measurement. Contributions to W_i's will be discussed later.

The coefficients p and q are determined by setting the first derivatives of X^2 with respect to p and q, dX^2/dp and dX^2/dq, equal to zero and solving the resulting pair of equations in the usual manner:[5] The two first derivatives are re-written in a matrix form, AX=B, where A is a 2x2 matrix. The inverse of A is found, and the coefficients are determined from $A^{-1}A\ x = A^{-1}B$, or $x = A^{-1}B$. Expressions for p and q are:

$$p = \frac{1}{D}\left[(\sum C_{2i}{}^2 W_i)\ (\sum E_i C_{1i} W_i) - (\sum C_{1i} C_{2i} W_i)(\sum E_i C_{2i} W_i)\right]$$

$$q = \frac{1}{D}\left[(\sum C_{1i} C_{2i} W_i)\ (\sum E_i C_{1i} W_i) - (\sum C_{1i}^2\ W_i)\ (\sum E_i C_{2i} W_i)\right]$$

Where D is:

$$D = (\sum C_{1i}{}^2 W_i)\ (\sum C_{2i}{}^2 W_i) - (\sum C_{1i} C_{2i}\ W_i)^2$$

Elements of the inverse matrix yield variances for p and q and the covariance:

$$\mathrm{var}(p) = (\sum C_{2i}{}^2 W_i)/D$$

$$\mathrm{var}(q) = (\sum C_{1i}{}^2 W_i)/D$$

$$\mathrm{covar}(p,q) = (\sum C_{1i} C_{2i} W_i)/D$$

The weighting factors (variances of individual measurements) have been assigned three components, based on the equation for E and on previous experience:

$$W_i \left[= p\ \mathrm{var}(C_{1i}) + q\ \mathrm{var}(C_{2i}) + \mathrm{var}(E_i)\right]^{-1}$$

Where "var(x)" represents the variance of x (square of the uncertainty of x).

The variance of the enrichment, $Var(E_i)$ is the square of the enrichment uncertainty, $\sigma_E{}^2$, where σ has been determined from mass spectrometry, chemical analysis, or other means.

Since the weighting factors depend on p and q, the calculation should be performed iteratively. Figure 3 shows a listing of a short BASIC language program used to calculate p and q values.

Use of the weighting factors is recommended for all calibrations. While it is possible to omit the weighting, experience has shown that large uncertainty variations often exist between measurements. For example, data measured using different counting time intervals have different uncertainties associated with them. Moreover, the standards available to the analyst often include a "blank" (zero enrichment) and several others; each of these standards may have different uncertainties associated with their respective enrichments. Use of the weighting factors will assure that variations in the quality of standards is considered during the calibration. Since many measurements eventually become "standard analysis procedures" at nuclear facilities, including the weighting will address those unusual (hopefully!) cases where sizeable variations exist in the calibration measurements uncertainties. For "normal" situations, the magnitude of the Wi's will be comparable (and weighting could be omitted).

Other sources of uncertainty which might be included in the Wi's are: operator errors, uncertainties associated with a specific measurement station, etc. Some of these effects must be determined by actual measurements. Uncertainties reported in the literature which are based on laboratory tests are sometimes much lower than those achievable in a fuel handling facility!

Assigning values to the uncertainties of the C_{1i}'s and C_{2i}'s is more complex. One common method is simply to make several measurements on the sample and calculate the mean values C_{1i} and C_{2i} and standard deviations from the means. Unfortunately, time constraints often do not permit a sufficient number of measurements so that the calculated standard deviation accurately represents the count rate uncertainties. In particular, computing these uncertainties from 2-3 measurements performed in a production environment will lead to large variations in uncertainty, with many results smaller than the actual uncertainly. It is better to calculate uncertainties based on counting statistics and assumed systematic errors. The variance of C_{1i} and C_{2i} can be divided into two terms:

$$\mathrm{var}(C_i) = C_i/t + \mathrm{var}\ (\mathrm{systematic})$$

The first term is due to counting statistics[6] where C_i is the count rate (dropping the 1 or 2 subscript) and t is the counting time interval. Generally, this term is the only one over which the operator has control; the (Ci/t) term may be reduced by extending the counting time. The second term, due to systematic errors, is more difficult to predict. In practice, these terms can be determined experimentally from a large ($\geq$ 50) number of measurements of a sample of known enrichment and extrapolated to all future measurements. This extrapolation assumes that the measurement techniques, environmental factors, etc. which gave rise to the systematic variance remain constant over a long period. Generally, the assumption is valid. It is important that those aspects of the measurement over which the analyst has some control be maintained constant: detector efficiency, amplifier gain, collimator-sample geometry, and SCA windows. The instrumentation must be designed to minimize the effects of electric power variations, temperature, and nearby fuel handling operations over which the analyst has little control. Once these potential sources of additional measurement uncertainty are characterized, constant systematic variance can be used.[10]

A convenient method of estimating the total uncertainty of a counting measurement, C_i, involves plotting the distribution of values as a histogram of "number of occurrences" vs count rate. Such histogram should yield the familiar Gaussian shape. If it does not, too small a sample of data has been used or more serious problems exist. (If the curve is clearly not Gaussian for a large sample, the assumptions behind the handling of measurement variances may not be valid). An accurate estimate of parameters C_o and s can be calculated using simple methods[7] in which the count data is fit to a Gaussian function:

$$Y(C_i) = Y_o\ [\exp-(C_i - C_o)^2\ /2s^2]$$

Where:
Y_o = height of the curve
C_o = mean value of count rates C_i
s = standard deviation

The mean value C_o is useful in tracking "drift" of the instrumentation over long periods (months to years). The standard deviation, s, is used to compute the systematic variances:

$$s^2 = (C_o/t) + \mathrm{Var\ (systematic)}$$

for each enrichment and counting SCA; "C_o" refers to the mean value of "C_1" or C_2"

Determination of the systematic variance should be made using samples of at least three different enrichments. A straight line is fit to the count rate variance vs (C_o^2) for each counting channel C_1 and C_2:

$$\mathrm{Var(systematic)} = (\mathrm{bias})^2 + [(C_o)(\text{rate dependent uncertainty})]^2$$

Where the (bias)^2 is a constant term and the (rate dependent uncertainty)^2 is the line's slope. (This treatment is similar to that discussed in reference 6). In most cases, the bias will be very small, and the rate dependent term may be insignificant in comparison to the variance due to counting statistics.

The "large" sample of data required to compute the systematic variances may be taken from previous measurements. This eliminates the need for lengthy calibration measurements and also accounts for long-term "drift" in the counting instrumentation. (Such drift may be significant; for an example see figure 6 of reference 10). Use of actual data also accounts for uncertainties which result from operation of the counting system in a "production" environment.

Once a good estimate of the systematic variance has been determined, suitable weighting factors can be calculated for use in determining the calibration factors p and q via the iterative calculations. Having values of p and q, there are two methods to determine the "goodness" of the fit: 1) plot the calculated enrichment vs the "book" value, and 2) calculate a X^2 value and compare it with tabulated values of X^2 for N-2 degrees of freedom. The latter method is more rigorous, but the plot identifies any "large" deviations of individual measurements. Examining the plot is adequate for routine calibrations.

"Unknown" enrichments may be determined:

$$E = pC_1 - qC_2$$

$$\mathrm{Var\ (E)} = C_1^2\ \mathrm{Var(p)} + p^2\ \mathrm{Var}(C_1) +$$

$$C_2^2\ \mathrm{Var(q)} + q^2\ \mathrm{Var}\ (C_2)$$

$$-2pq\ \mathrm{(covariance)}$$

The measured enrichment uncertainty is $[\mathrm{Var(E)}]^{1/2}$; for most safequards measurements, the limit of effor, L.E. = $2[\mathrm{Var(E)}]^{1/2}$ is reported.

An Example

The calibration and "unknown" determination calculations proposed here may be demonstrated using some uranium oxide pellet measurements.[8] These pellets were assayed using an Eberline RD-19 detector[9] and BSAM[4] instrumentation. No estimates of the systematic Variances were available, so a bias of 0.01 and a count rate dependent variance of [0.02(count rate)]^2 were assumed for both C_1 and C_2. The "book value" enrichment uncertainty was stated to be ± 0.04% (1-sigma) based on chemical analysis results. Table 1 shows the measurement data and variances for 8 "standard" samples.

Table 1: Uranium Oxide Pellet Counting Data

Enrichment	Channel 1 Total Counts	C_{1i}	Var(C_{1i})	Channel 2 Total Counts	C_{2i}	Var(C_{2i})	Count Time (sec)
Background (0.0)	5269	2.40	3.49×10^{-3}	6560	2.98	5.02×10^{-3}	2198.0
19.87	15434	9.41	4.13×10^{-3}	6746	4.11	9.38×10^{-3}	1640.0
4.04	13250	4.67	1.04×10^{-2}	11984	4.22	8.71×10^{-3}	2840.0
12.5	17636	6.84	2.14×10^{-2}	10691	4.14	8.50×10^{-3}	2579.9
Background	10246	2.39	2.94×10^{-3}	12861	3.00	4.40×10^{-3}	4286.0
9.52	16344	6.05	1.70×10^{-2}	11036	4.09	8.30×10^{-3}	2699.8
5.03	14412	5.02	1.19×10^{-2}	12334	4.30	8.99×10^{-3}	2870.0
Background	9967	2.37	2.91×10^{-3}	12557	2.99	4.39×10^{-3}	4200.0

The calibration was solved iteratively, as previously described, starting with $p = 1 \pm 0.0$ and $q = 0.0 \pm 0.0$, using the short BASIC language program listed in figure 3. The calculation required 3-4 iterations to compute the coefficients:

$p = 3.277$; $\mathrm{Var}(p) = 1.350 \times 10^{-3}$

$q = 2.612$; $\mathrm{Var}(q) = 2.484 \times 10^{-3}$

Covariance = 1.680×10^{-3}

The enrichments of the eight samples were calculated to check the coefficients and determine typical enrichment uncertainties. These results are shown in Table 2.

Table 2 Measured Enrichments

Enrichment ("book" value)	Enrichment ± L.E. (assay value)
0.0	0.08 ± 0.54
19.87 ± 0.04	20.1 ± 0.98
4.04 ± 0.04	4.28 ± 0.93
12.5 ± 0.04	11.6 ± 1.20
0.0	-0.002 ± 0.50
9.52 ± 0.04	9.14 ± 1.10
5.03 ± 0.04	5.22 ± 0.98
0.0	-0.04 ± 0.50

The agreement between "book" and assay values is good, as expected.

Although single channel analyzer based counting systems have been used for many years for safeguards measurements, data analysis techniques are often primitive. Careful inclusion of all count rate uncertainty sources in the initial data reduction and the use of a range of calibration samples are necessary to achieve reasonable results for measurements of "unknown" samples. The techniques presented here have been tested and found to be an improvement over previous methods. In particular, the use of more than two samples in generating calibrations and the determination of uncertainties in calibration coefficients are significant advantages of the present method.

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```
5 REM PROGRAM TO COMPUTE SCA COEFFICIENTS FOR ENRICHMENT CALIBRATION
10 DIM C1(10),VC1(10),C2(10),VC2(10),E(10)
20 REM ENRICHMENT VARIANCE
30 VE=(.04)^2
40 REM SET INITIAL VALUES
50 ITER=1
60 P=1
70 VP=0
80 Q=0
90 VQ=0
100 REM INPUT COUNTING DATA
110 PRINT "HOW MANY DATA?"
120 INPUT N
130 FOR I = 1 TO N
140 PRINT "ENTEER C1,VCC1,C2,VC2,E"
150 INPUT C1(I),VC1(I),C2(I),VC2(I),E(I)
155 PRINT C1(I),VC1(I),C2(I),VC2(I),E(I)
160 NEXT I
170 REM BEGIN ITERATIVE FIT
180 PRINT "ITERATION NUMBER",ITER
190 MA=0
200 MB=0
210 SAA=0
220 SAB=0
230 SBA=0
240 SBB=0
250 REM SUMMATIONS
260 FOR I=1 TO N
270 WT=1/(P*VC1(I)+Q*VC2(I)+VE)
275 PRINT "WT",I,WT
280 SAA=SAA+CC2(I)*C2(I)*WT
290 SAB=SAB+C1(I)*C2(I)*WT
300 SBB=SBB+C1(I)*C1(I)*WT
310 MA=MA+E(I)*C1(I)*WT
320 MB=MB+E(I)*C2(I)*WT
330 PRINT MA,MB
340 PRINT SAA,SAB,SBB
350 NEXT I
360 REM CALCULATE COEFFICIENTS
370 SBA=SAB
380 D=SAA*SBB-SAB*SBA
385 PRINT "DET",D
390 REM COEFFICIENTS
400 P=(SAA*MA-SAB*MB)/ D
410 VP=SAA/D
420 Q=(SAB*MA-SBB*MB)/D
430 VQ=SBB/D
440 COV=SAB/D
450 REM DISPLAY RESULTS
500 PRINT "P",P,"VP",VP
510 PRINT "Q",Q,"VQ",VQ
520 PRINT "COVAR",COV
550 ITER=ITER+1
580 INPUT XYZ
600 GOTO 180
610 STOP
620 END
```

Figure 3. Computer program for calculating coefficients "p" and "q".

```
5 REM INITIAL RATE CALCULATIONS
10 PRINT "INPUT TOTALS--1,TOTALS--2,COUNT TIME"
20 INPUT CA,CB,T
30 REM SYSTEMATIC VARIANCES..SET PRIOR TO USE
40 B=.01
50 R=.02
60 REM COMPUTE COUNT RATES
70 CA=CA/T
80 CB=CB/T
90 REM COMPUTE VARIANCE
100 VA=CA/T + B*B + R*R*CA*CA
110 VB=CB/T + B*B + R*R*CB*CB
120 PRINT "C1",CA,"VAR(C1)",VA
130 PRINT "C2",CB,"VAR(C2)",VB
140 GOTO 10
150 STOP
```

Figure 4. Program to calculate count rates and variances from total counts.

```
5 REM CALCULATE "UNKNOWN" ENRICHMENTS
10 PRINT "ENTER P, VAR(P), Q, VAR(Q), COVAR"
20 INPUT P,VP,Q,VQ,VV
30 PRINT "P",P,"VP",VP
40 PRINT "QQ",Q,"VQ",VQ
45 PRINT "COVARIANCE",VV
50 REM COMPUTE  ENRICHMENTS
100 PRINT "ENTER  C1, VAR(C1), C2, VAR(C2)"
105 INPUT C1 ,VC1,C2,VC2
110 E=P*C1-Q*C2
120 VE = C1*C1*VP + P*P*VC1 + C2*C2*VQ + Q*Q*VC2 - 2*P*Q*VV
130 LE=2*SQR(VE)
140 PRINT "ENRICHMENT=",E,"+/-",LE
150 GOTO 100
160 STOP
170 END
```

Figure 5. Program for calculating unknown enrichments and Limits-of-Error (LE's).

COMMUNITY RESPONSE TO LOW-LEVEL RADIOACTIVE WASTE: A CASE STUDY OF AN ATTEMPT TO ESTABLISH A WASTE REDUCTION AND INCINERATION FACILITY

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ABSTRACT

The Federal Low-Level Radioactive Waste Policy Act of 1980 specified a 1986 deadline for the establishment of state and regional low-level radioactive waste disposal sites. There is little optimism that the deadline will be met. Morris K. Udall has introduced Bill HR 1083 in Congress which proposes extending the deadline to 1993 and specifying a 40 percent reduction in the volume of wastes shipped.

Waste volume can be reduced through incineration and compaction technologies. However, it may be as difficult to convince communities that a waste treatment facility is a good investment as it is to convince them that a disposal site is worth having. In other words, the waste volume reduction argument may ultimately depend on cutbacks in the nuclear industry.

This research reports one community's response to the possibility of a local low-level radioactive waste compaction and incineration facility. The case is especially interesting because the community needs new industries and has a history of living with a nuclear materials facility. In spite of that the community's response was quite negative, fueled by a vocal local opposition group and anti-nuclear activists.

Survey data indicates that despite general opposition people still feel the need for more information on radioactive materials and are willing to attend education sessions if the time and place are convenient. Suggestions are given for those considering future attempts to establish low-level radioactive waste reduction facilities.

INTRODUCTION

The Federal Low-Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) requires states to assume responsibility for the disposal of low-level radioactive wastes produced within their borders as of January 1, 1986. Congress encouraged the formation of regional compacts as the most efficient and safe method to handle the Nation's low-level radioactive waste (Jordan, 1984). However, it is increasingly obvious that the January 1, 1986 deadline will not be met (Gettinger, 1985). There are three primary reasons for the delay: first, states have little precedence in regional cooperation and balk at becoming a radioactive waste dumping ground for their neighbors; second, politicians' fear of public reaction has pressured many of them to adopt an adamant "not in my backyard" defensive strategy (for an example of this problem in the Northeast, see Loth, 1984); third, states which are earnestly pursuing the establishment of waste sites are developing extensive citizen involvement programs which will certainly prolong the process but which may not insure community acceptance (see, for example, Texas Advisory Commission on Intergovernmental Relations, 1985).

One response to this impasse has been a bill (HR 1083) introduced into Congress by Morris K. Udall requesting an extension of the 1986 deadline to 1993 with a stipulation that the present volume of shipped waste be reduced by 40 percent (Gettinger, 1985). However, volume reduction poses its own problems which may be just as difficult to solve as the problems engendered by the Federal Low-Level Radioactive Waste Policy Act of 1980. Waste volume can be reduced either by a cutback in the production of waste or by compaction and incineration procedures. A cutback in production is unlikely in the short run, although antinuclear activists see the waste issue as the most effective means by which to shut down nuclear power plants (Loth, 1984), and compaction and incineration run head-on into the public acceptability issue again.

The research reported here is a summary of one community's response to the concept of a low-level radioactive waste reduction facility. The response by vocal elements of the community was both swift and negative, somewhat to the

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surprise of the sponsoring company. Data gathered under contract to that company provides an instructive profile of community sentiment. Suggestions for more effective approaches are made.

THE RESEARCH SETTING AND PROCEDURES

In late Fall, 1984 a nationally known, and locally familiar, nuclear industrial firm announced its plans to construct a low-level radioactive waste reduction facility on land it owned within a cluster of small communities in Southwestern Pennsylvania. This company had operated a nuclear materials industry in the area for many years. The firm's initial mood was entirely positive because it perceived a strong base of local support related to its past industrial involvement in the area and because of the need for local job opportunities in the face of declining traditional industries. For these reasons the company did not anticipate the need for special community involvement programs although it did contract with a University team to do a local survey and to provide some public education on radiation programs. Initial news reports on the proposed facility were also upbeat and stressed the need for new jobs and revenue.

However, within days of the public announcement a local protest group, calling itself the "Kiski Valley Coalition to Save Our Children," surfaced and began organizing public meetings and television and newspaper campaigns. The public meetings included, at various times, local government officials, representatives of the Nuclear Regulatory Commission and the State Department of Enviromental Resources, and anti-nuclear activists well-known in Pennsylvania. Although invited, company officials initially declined to attend these meetings but later sent representatives to several of them. This initial hesitancy to get involved with the protest group brought criticism from the news media. These meetings were well attended by those opposing the proposed facility and their position tended to prevail because other points of view were simply not tolerated. One individual threatened to pull out his local industry if the waste reduction facility came in, others vowed to lie in front of the bulldozers if necessary, and the local media painted an ongoing bleak picture of public receptivity to the proposed facility. Meanwhile, rumors circulated freely about possible past nuclear materials mismanagement by the company. The opposition group went to great lengths to try to cast doubt on the company's credibility.

Just prior to the creation of the "Kiski Valley Coalition to Save Our Children" the survey comprising the bulk of this research report was undertaken to assess various aspects of local public opinion concerning the waste treatment facility. The results of that survey, while confirming deep public concern, highlights aspects of public opinion which may be useful to focus upon in future attempts to establish facilities of this type.

QUESTIONNAIRE DESIGN

The questionnaire included both open ended and structured questions. The structured questions focused on the following dimensions:

1. Local concern about possible water, soil, and air contamination resulting from operation of the facility. Also, concern about possible radiation releases from truck mishaps, the level of threat LLRW poses to the community, and fear that the proposed facility may be a "foot-in-the-door" for an eventual disposal facility.

2. Judgments about the likelihood that air, water, and soil contamination will occur.

3. The degree of trust of three organizations: the company, the Nuclear Regulatory Commission (NRC), and the State Department of Environmental Resources (DER).

4. General concern about property values, increased truck traffic, the ability of local emergency teams to handle problems, the possibility that industries dealing in other hazardous materials may be attracted to the area, and the perceived threat to local fish and wildlife.

5. Questions dealing with economic issues: the importance of creating jobs locally; the importance of new local industries even if they deal with hazardous materials; the trade-off between new industries and public health and safety; estimations of the economic value of such a facility to the community.

6. Questions asking whether the respondent would like to know more about specific issues and whether he or she would attend education sessions given in the local area.

7. Demographics including, age, sex, marital status, education level, length of residence in the local area, occupation, home ownership, and the presence or absence of children at home.

In addition, two open-ended questions were included: one asked what specific aspects of radiation bothered the respondent and the other encouraged the respondent to make any comments that they felt were important.

THE SAMPLE AND RETURN RATE

A sample of 200 names was randomly drawn from the ALLTEL telephone directory for the area within a ten-mile radius of the proposed facility. This area has a combined population of 17,421 according to 1980 census data.

The 200 questionnaires were mailed just several days prior to the emergence of the local protest group. The initial return was encouraging since forty questionnaires were received within the first two weeks. A follow-up letter was mailed to thank those who had responded and to encourage those who had not yet done so.

In the meantime, anti-nuclear activism had heated up in the area and letters began appearing in local newspapers challenging the impartiality of the survey, because of company sponsorship, and urging citizens not to respond. However, completed questionnaires continued to trickle in until a total of 77, or 39 percent of the initial mailing, had accumulated.

Given the initial surge of returns and rapid drop off after the local protest group mobilized it seems logical to assume that the return rate was affected by the hostility and suspicion engendered by the protest group. However, it is important to note that the initial returns did not systematically vary in content when compared with later returns. There is no statistically significant difference between responses on the first wave of questionnaires and those coming later.

SURVEY RESULTS

Demographic Profile of the Sample: Table 1 summarizes the measured characteristics of those returning the questionnaire. The sample is disproportionately male, older, married, relatively well educated, home owners who are long-time residents of the area, and middle to upper-middle class or retired. A slight majority of respondents have children living at home. It should be noted that the area covered by the sample tends to be older with 19 percent of the population in 1980 being over 65. Only 19 percent of the sample can be characterized as blue-collar workers.

It is difficult, on an a priori basis, to predict how a sample of this kind will respond to questions involving a low-level radioactive waste treatment facility. In past research involving radiation risks women tend to be more fearful than men, older people are somewhat less fearful than those younger and middle aged, those with children tend to be more fearful than those without, and occupational prestige and level of education tend to have a mixed relationship to fear of radiation (Kasperson, et al., 1979). The data on these issues will be presented later. First, an overview of the attitude questions is necessary to set the stage for further discussion.

INTENSITY OF CONCERN

Table 2 presents the percentage distribution of responses to six items measuring the following facets of concern:

Question 1: Concern that radiation might contaminate local water supplies.

Question 2: Concern that radiation might contaminate the soil.

Question 3: Concern that radiation might contaminate the air.

Question 4: Concern that radiation might be released in truck mishaps.

Question 5: Perceived level of threat to the community.

Question 6: Fear that this facility is the first step toward a full-blown disposal site.

Table 2 illustrates that a substantial majority of the respondents express the highest levels of concern on all issues. If the top two levels express considerable concern on every issue. Also worthy of note is that of the five types of contamination, airborne contamination elicits the highest level of concern.

JUDGMENTS OF THE LIKELIHOOD OF ACCIDENTS

Another dimension which may be important in trying to assess peoples' concerns is how probable they think an accident of a particular type might be. It is one thing to be highly concerned but if you feel the probabilty of the feared event is low it may moderate your negative response. Table 3 presents the percentage distribution of responses to items requesting judgments of "how likely" radiation contamination is from the water (1B), the soil (2B), the air (3B), and from truck accidents (4B).

When compared with Table 2 it is clear that not as many respondents picked the most extreme response in Table 3. However, a large majority express the judgment that each of these events is likely to occur. As in Table 2 it is clear that air contamination is viewed with greater trepidation than the other types of contamination.

TRUST OF INSTITUTIONS INVOLVED IN THE PROPOSED PROJECT

A factor which also enters into people's judgment of technological risks is the level of trust they have for those whose responsibility it is to manage the risky material. In recent years research has demonstrated a declining base of public trust in industrial organizations who produce risky technologies and regulatory agencies charged with enforcing state and federal laws regarding safe handling and management of these materials (Nelkin, 1979).

Three questions were included which asked respondents if they felt they could trust the company (Q1), the Nuclear Regulatory Commission (Q2), and the State Department of Environmental Resources (Q3) to see to it that the facility is run safely. Table 4 presents the percentage of people responding to levels of each of those questions.

The content of Table 4 supports past research indicating that a majority of respondents

Table 1: Percentage Distribution of the Sample's Demographic Characteristics (N=77).

AGE	
Under 21	01%
21-29	10%
30-39	25%
40-49	14%
50-59	20%
60+	30%
	100%

SEX	
MALE	68%
Female	32%
	100%

MARITAL STATUS	
Never Married	09%
Married	71%
Widowed	16%
Separated-Divorced	04%
	100%

LEVEL OF EDUCATION	
Grade School	13%
High School	39%
Some College	20%
2 Year Degree	05%
4 Year Degree	09%
Beyond 4 Year Degree	13%
Missing	01%
	100%

LENGTH OF TIME IN COMMUNITY	
Under 1 Year	01%
1-5 Years	08%
6-10 Years	09%
10 Years & Over	82%
	100%

CHILDREN LIVING AT HOME	
Yes	55%
No	45%
	100%

HOUSING STATUS	
Own Home	84%
Rent	16%
	100%

OCCUPATION	
Executive, Administrator, Professional	19%
Technical, Clerical, Services	22%
Craft, Repair, Operators, Transportation	19%
Retired	14%
Housewife	12%
Student	01%
Missing	13%

Table 2: Percentage Distribution of the Concern Responses (N=77)

	Questions					
Level of Concern	1	2	3	4	5	6
Very Concerned	69%	71%	77%	74%	53%	81%
Somewhat Concerned	22%	17%	14%	16%	30%	8%
Not Too Concerned	4%	7%	3%	9%	13%	10%
Not At All Concerned	1%	1%	3%	1%	4%	1%
No Response	4%	4%	3%	0%	0%	0%
	100%	100%	100%	100%	100%	100%

Table 3: Percentage Distribution of the "Likelihood" Items (N=77)

	Questions			
How Likely Is Contamination	1B	2B	3B	4B
Very Likely	57%	58%	68%	57%
Somewhat Likely	26%	30%	22%	31%
Not Too Likely	12%	8%	5%	12%
Not at all Likely	1%	0%	1%	0%
No Response	4%	4%	4%	0%
	100%	100%	100%	100%

Table 4: Percentage Distribution of the Trust Questions. (N=77)

	Questions		
Level of Trust	Q1(Company)	Q2(NRC)	Q3(DER)
Very Trustworthy	5%	7%	10%
Somewhat Trustworthy	26%	32%	34%
Not Too Trustworthy	31%	32%	26%
Not At All Trustworthy	31%	26%	27%
No Response	7%	3%	3%
	100%	100%	100%

Table 5: Percentage Distribution of Answers to the Economic Questions (N=77)

	Questions	
Importance	Q1(Jobs)	Q2(Hazardous Industry)
Extremely Important	62%	20%
Somewhat Important	25%	18%
Not Too Important	8%	14%
Not At All Important	4%	44%
No Response	1%	4%
	100%	100%

	Question
Importance	Q3 (Public Health vs New Industry)
The Most Important Issue	83%
Important But Not As Important As Other Local Issues	16%
Nothing To Worry About At All	0%
No Response	1%
	100%

Estimates of Payoff	Questions Q4(Create Enough Jobs)	Q5(Bring in Money)
Probably	11%	13%
Probably Not	88%	86%
No Response	1%	1%
	100%	100%

Table 6: Percentage Distribution of Responses to the General Concern Questions (N=77)

Level of Perceived Threat	Q1(Property Values)	Q2(Truck Traffic)
No Threat At All	1%	9%
Small Threat	14%	10%
Moderate Threat	17%	31%
High Threat	65%	47%
No Response	3%	3%
	100%	100%

Level of Concern	Q3(Attract Other Industry	Q4(Fish & Wildlife)
Very Concerned	38%	34%
Somewhat Concerned	47%	56%
Not Too Concerned	11%	6%
Not At All Concerned	0%	0%
No Response	4%	4%
	100%	100%

Q5 (Ability of Fire and Emergency Teams to Handle Emergencies)	
They Can Handle Most Emergencies Safely	13%
They Can Handle Some Emergencies Safely	27%
They Can Handle Few Emergencies Safely	30%
They Can Hardly Handle Any Emergencies Safely	26%
No Response	4%
	100%

express little trust in either the company, the NRC, or the State DER. In this case the DER engenders slightly more trust than does the company or the NRC. This may reflect some respondents' beliefs that the DER may be less cavalier with radiation hazards than those whose business involves nuclear materials. This point was made in public meetings organized by the opposition group.

ECONOMIC FACTORS INVOLVED IN DECISIONS CONCERNING THE PROPOSED FACILITY

Because this region is somewhat economically depressed it seemed reasonable to assume that local citizens would be sensitive to the possibility that this new industry would generate jobs and revenue. In fact, early newspaper coverage of the proposed facility indicated that local citizens would welcome it precisely for that reason.

Five questions dealt with economic issues. Question 1 asked about the importance of creating more jobs locally; Question 2 dealt with the importance of attracting new industries even if they deal with hazardous materials; Question 3 asked whether public health and safety was the most important consideration relative to new industries; Question 4 asked whether the respondent thought that the proposed facility would create enough jobs to make it worthwhile to the community; Question 5 inquired whether the respondent thought that the proposed facility would bring in enough money to make it worthwhile to the community. Table 5 presents the percentage distribution of answers to these questions.

Interpretation of Table 5 is very straightforward. Although residents of this area think that the generation of jobs locally is extremely important they are not willing to jeopardize public health and safety in the process of boosting the economy. However, they also do not believe that the proposed facility is going to be much of a local economic boon. In other words, the perceived rewards-minus-costs outcomes of the proposed facility are not enough to establish perceptions of equity in this community.

OTHER ISSUES OF CONCERN

A number of other general concern questions were asked involving threats to property values (Q1), increased truck traffic as a threat to public safety (Q2), fear that this facility might attract other industries dealing in hazardous materials (Q3), the facility as a threat to local fish and wildlife (Q4), and the ability of local fire departments and emergency teams to handle any emergencies that may arise as a result of the operation of the proposed facility (Q5). Table 6 presents the percentage distribution of responses to these items.

Table 6 demonstrates that community reaction to this proposed facility is compounded by a number of concerns not directly tied to fears of radiation. The vast majority of respondents are very concerned about property values, increased truck traffic, the ability of fire and emergency teams to handle possible emergencies, other hazardous materials industries viewing the area as fair game, and the impact on fish and wildlife.

INTEREST IN RECEIVING MORE INFORMATION ABOUT RADIATION HAZARDS

Finally, it was felt that an important element in citizen response to the proposed facility might be their willingness to hear more about the issues that concern them most. After each of the questions dealing with concern for, and the likelihood of, contamination of water, soil, air, and from truck mishaps the following question was asked: "Would you like to know more about his issue?" Q1 deals with water contamination, Q2 with soil contamination, Q3 with air contamination, and Q4 with releases from truck mishaps. Table 7 presents the percentage distribution of responses to these items.

As indicated in Table 7, most respondents are interested in hearing more about these particular issues. However, it is difficult to determine whether this expressed interest in more information is a genuine openess or a desire to have another forum to publicize concerns.

At the end of the questionnaire respondents were asked whether they would attend radiation education-information sessions given by a team from a unviersity in their local area. This is a direct question about behavior in which personal costs can be easily assessed. Since these kinds of questions correlate highly with actual behavior the response should indicate real interest (Fishbein and Ajzen, 1975). Sixty percent of the sample said they would attend such sessions if they were offered at a convenient time and location. There apparently is still some open-minded interest in the risks posed by low-level radioactive waste.

RESPONSE TO THE OPEN-ENDED QUESTIONS

Two open-ended questions were included in the questionnaire. The first asked: "Please tell us what, if anything, frightens you about low-level radioactive waste." A full 82 percent of the respondents wrote answers to this question. There were basically five classes of responses to this question. First, and most frequent, respondents gave general emotional reactions of the nature that it will contaminate everything or that everything about it is frightening. Second, many people expressed distrust of the human element in the handling of risky materials. This kind of response often indicated that even if the technology is sound there would be problems due to human error. Third, many people expressed general concerns

Table 7: Percentage Distribution of Responses for Items Asking Whether Respondents Wanted More Information (N=77)

Do You Want More Info?	Q1(Water	Q2(Soil)	Q3(Air)	Q4(Truck Mishaps
Yes	70%	72%	73%	64%
No	20%	18%	17%	27%
No Response	10%	10%	10%	9%
	100%	100%	100%	100%

Table 8: Hierarchical Regression of Each Concern Question On All The Demographics (Reported as Cumulative R's)

Demos	Soil Contamination	Air Contamination	Water Contamination	Truck Mishaps
Sex	.27*	.22*	.23*	.25*
Age	.39*	.35*	.34*	.28*
Education	.39	.36	.34	.28
Occupation	.41	.38	.39	.30
Housing	.43	.39	.41	.34
Time in Community	.46	.40	.44	.34
Children at Home	.47	.40	.44	.34

* F-Ratio Significant at or Beyond .05 Level

about health which were not directly tied to cancer while a few specifically mentioned an unusually high cancer rate in the area and related it to past nuclear industry activities in the area. One respondent tied radiation hazards to heart disease and lung problems. Fourth, a number of people feel that there does not exist sufficient knowledge to handle this kind of material safely. Finally, birth defects and general concern for children was mentioned by 8% of the respondents.

In the pattern of responses noted above an interesting difference between the responses of males and females surfaced. Females were much more likely to express a general negative reaction, "everything about it scares me," while males were much more likely to mention human error specifically.

The final item on the questionnaire simply asked respondents to comment on anything they would care to. Responses to this general request ranged from tirades against the company, through criticisms of the questionnaire, to a discourse on the failure of early warning systems and the danger of nuclear attack. Most of the issues that surfaced in the first open-ended question were reiterated at this juncture. However, a few people mentioned the need for new industry and were critical of those protesting the proposed facility.

DEMOGRAPHIC CORRELATES OF THE VARIOUS RESPONSES

It is essential to examine respondent characteristics and their impact on the various questions so that public concerns can be further specified. An intensive analysis was done using cross tabulations and nonparametric statistics along with correlation and regression analysis using parametric techniques. In all cases the results are consistent and mutually supportive. Table 8 presents the results of a regression analysis in which each of the concern items, soil, air, water, and truck mishaps, are treated as dependent variables and the demographics as independent variables. For each dependent variable only sex and age contribute significantly to the total explained variance (simply square the multiple R's to get explained variance).

Clearly, the one factor which has an unambiguous impact on extremity of response is sex. More women consistently choose extreme concern responses than do men. Recall that in an earlier discussion the open ended question which asked respondents what particularly frightened them about radiation women were more likely to respond with a very global, emotional response such as: "Everything about it frightens me." This differential impact of sex is characteristic of most research done on public concern for radiation risks (Kasperson, et al., 1979).

The only other demographic characteristic which has a statistically significant relationship with the concern questions is age. People the extreme response than are those at other ages. An initial reaction to this result might be that older people tend to be less well educated and therefore the effect is actually the impact of differential education levels. However, a glance at Table 8 should convince the reader that education has little systematic impact on any of the concern questions. It is possible that older people are somewhat less concerned because long term health issues are somewhat irrelevant or because they are more comfortable with the unwanted by-products of industry having survived them for many years. This is, of course, conjecture. A number of older people specifically wrote about their fears for future generations and, in particular, for their grandchildren.

The other demographics bear little or no systematic relationship to the concern questions. None of the remaining relationships approach statistical significance.

SUMMARY AND CONCLUSIONS

There can be little doubt that the majority of these respondents are very negative toward the idea of a local low-level radioactive waste treatment facility. The first, and most crucial question that must be addressed is the degree of confidence that can be attributed to the results of this survey given the 39 percent response rate. Without doubt the sample is disproportionally male and older. However, since males tend to express somewhat less concern than females and older respondents somewhat less concern than younger respondents the effect on the results is a conservative one. That is, had the sample been more female and younger the negative tone of the results probably would have been even more pronounced.

The second question that must be dealt with is to what extent the emergence of an organized opposition group influenced people's attitudes as reflected in the questionnaire results. As noted previously, 52 percent of the questionnaires were returned prior to public notification of the existence of the "Kiski Valley Coalition to Save Our Children." There were no statistically significant differences between the responses on those questionnaires and the remaining 48 percent. The pattern of results appears to be a solid indicator of local community attitudes and beliefs.

It seems reasonable to assume that getting local communities to accept radioactive waste treatment facilities is going to be about as difficult as getting them to accept radioactive waste disposal facilities. Both are viewed as very hazardous and as bringing few rewards to compensate for the costs they bring with them. However, this case study illustrates several points that future facility developers should attend to:

1. Never underestimate the public's fear of radioactive products in general and waste in particular. In the present climate of fear induced by media attention to chemical waste dumping problems and deaths from toxic chemical accidents intense opposition should be the expected response.

2. Companies should never assume that their past performance record, or public relations programs, will carry them through when the issue is radioactive risks. Companies, like families, have dirty linen that will be aired by someone who wants to discredit them. It may well be that even the most impeccable performance record cannot overcome public fears in today's climate of opinion.

3. However, our data clearly indicate that a majority of respondents are willing to put themselves out to get more information on the issue of low-level radioactive waste. The sincerity of these respondents is evidenced by their not being those who check the most extreme responses. These tend to be the more moderately negative people. As is well known in political circles the moderates are precisely those people who are amenable to reasoned argument and debate. Information and education programs must be part of a public involvement package antedating any dogmatic company pronouncements about the establishment of such a facility.

4. At the public protest meetings the point was made repeatedly that the company had not consulted with the community during the early planning stage. Companies should give consideration to consulting and negotiation processes in dealing with local communities. Studies done by the Institute for Research on Land and Water, Penn State University (1983) and by the Texas Advisory Commission on Intergovernmental Relations (1985) spell this process out in great detail.

5. Our data also indicate that people do not perceive radioactive waste treatment facilities as generating sufficient jobs or revenue to make them worth the community's consideration. Compensation and incentive programs, which are now being considered for all radioactive waste disposal programs, may be necessary to elicit community support.

6. Finally, state and national anti-nuclear groups are involved in communication networks which insure that their spokespersons will eventually be involved in any activity involving radioactive waste. Planning for that exigency should be part of any program involving the treatment or disposal of radioactive waste.

This research indicates that waste reduction facilities are likely to face opposition as intense as that encountered by low-level radioactive waste disposal sites. Those interested in establishing such facilities should carefully consider community involvement and incentive plans which have been constructed with disposal siting in mind.

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