CONTENTS

INMM

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Dr. Higinbotham

EDITORIAL

More Crash Studies Coming

By W.A. Higinbotham
Brookhaven National Laboratory
Upton, Long Island, N.Y.

Writing editorials these days is a big gamble. What might be relevant at noon today may be irrelevant by 8 a.m. tomorrow. Perhaps some comments on past history will still be relevant when this gets published.

The subject of proliferation of nuclear weapons is as old as the subject of nuclear fission. It was much on my mind when I decided to go to Los Alamos in the fall of 1943. The implications for world security and for U.S. policy were discussed in a report prepared for consideration by the Government by scientists at the secret University of Chicago laboratory in the fall of 1944.

Following Hiroshima and Nagasaki, the U.S. pursued two policies, one to design a system for world control of nuclear energy and the other to continue research on and production of nuclear weapons. At the same time that **Bernard Baruch** presented the U.S. proposal for world control of the atom to the United Nations, people from all major nations were invited to observe a demonstration of nuclear weapons at Bikini atoll in the Pacific.

The Baruch proposals were novel indeed. They assumed that nuclear energy would be important to the world in the future, recognized the relationship between nuclear power and nuclear weapon technology and proposed that all nuclear technology, which might in national hands be subverted for military purposes, be conducted only by an International Atomic Development authority. The goal was to achieve a world without nuclear weapons and with an international agency to provide timely warning of national moves to "go nuclear."

For a number of reasons, this U.S. initiative was unsuccessful. It was very ambitious. It might not have worked. It would have been an exciting experiment, though.

That scheme is no longer viable. There are five major nuclear weapon powers. Knowledge of the technologies for reactors, enrichment, reprocessing and even weapons is widespread. Measures to reduce the nuclear arms race and to contain proliferation are no less important, but they will have to apply to the world as it is today.

Some other historic milestones were President **Eisenhower's** atoms for peace speech to the U.N. in 1953, establishment of the International Atomic Energy Agency in 1956, the nuclear test ban agreement of 1963 and the Non-proliferation Treaty of 1970. In 1970, it seemed as if proliferation should be contained by the NPT and by the IAEA safeguards. However, India tested a nuclear "device" in 1974 and now there is great concern about diffusion of enrichment and reprocessing technology, even under IAEA safeguards. More and more people in more countries are becoming opposed to nuclear power. What will happen?

One prediction seems very safe: there will be more crash studies! Some relaxed contemplation is also in order. Unfortunately, that isn't funded.

Cardwell

THE INMM CHAIRMAN SPEAKS

MULES, FOX HUNTING, AND THE CRBR

By Roy G. Cardwell, Chairman
Institute of Nuclear Materials Management, Inc.

"There is no moral justification for an energy policy that would cause unemployment."

Thus spoke McCormack* in a sobering appraisal of energy and foreign policy to the Foreign Service Institute of the U.S. State Department.

And the congressman is quite correct. Our annual growth rate in energy in recent years has been 3.6 percent. If we apply hard conservation measures to bring this down to a 2.0 to 2.5 percent annual increase, we will still double our energy consumption in from 20 to 35 years.

Yet, at this moment, we here in Oak Ridge are suffering the pains of an eminent threat by the new administration to scrap the Clinch River Breeder Reactor, a high point in the 25-year U.S. breeder development program. Why? Plutonium. The mystical hybrid that produces more fuel while burning itself could *potentially* be used to make bombs or pollute the environment.

Never mind that CRBR's production of plutonium will be only one-third that of any other U.S. nuclear plant or that nearly every other industrialized nation already has breeders in operation. Never mind that the plutonium we now have on hand in the breeder program would produce five times as much electricity as the total of all OPEC oil. Never mind that our natural uranium supplies will last only into the latter of this century. The breeder is, to paraphrase the recent Ford Foundation-sponsored panel report, "unnecessary" because "this country should realize that the world is not running out of energy."

This same panel, however, also concludes that nuclear power: (1) has *considerably less adverse effect on health and environment* than coal; (2) on the average poses *no greater accident risk* than coal; and (3) will continue to be, in general, *less costly* than coal.

It is obvious that the U.S. must greatly reduce its dependence on OPEC oil lest we be eventually led into an economic disaster. It is also an absolute shame to have to burn a material that gives us so many useful products. More than half the fibers for everything from carpets to coats come from petrochemicals, as well as 80 percent of our rubber. The construction industry depends on adhesives—plywood is a good example—as it does on paints and other coverings. From paper to ink, printing depends on petroleum. The aspirin, shampoo, soaps and detergents are all chemical products. Half the fertilizer that increases the world's crop yield comes from petroleum and natural gas. Shameful is a modest term at best.

On the other hand, our anti-nuclear conservationists should note that uranium and plutonium will yield only energy and take nothing away from our other needs.

McCormack says that only coal and nuclear can fill the gap for the remainder of this century. But the big effort needed to improve coal technology is just beginning, and the fuel at present is subject to many factors which make the price of its energy unstable and often unreasonable even where burning is still permitted.

The answer does not lie in the scrapping of a very promising stable energy source but rather in an approach that reminds me of a story my father used to tell about a great uncle who had a very mean mule. This mule was a large, powerful animal that was the prime source of energy for the farm's operation. He could perform with relative ease but had to be constantly directed and reprimanded by my uncle. When asked why he kept such an animal that was so much trouble, my uncle replied, "I can plow this fellow all day, take him out and fox hunt him all night, bring him back and turn him in the back field in the morning, and he'll kick up his heels and run around the barn!"

My uncle had such a strong, reliable source of energy that he was willing to put out a lot of extra effort to *manage* it. And so it is with nuclear. A forceful, active *management of nuclear materials* is needed—whatever is required to ensure that they remain in the proper hands and under the proper physical conditions—instead of scrapping a promising source of energy.

And that's what our profession is all about, isn't it?

*U.S. Rep. Mike McCormack, Washington.

Mr. Lee

New Member Total Stands at 69

By James W. Lee, Chairman
INMM Membership Committee

As we finish the third quarter of the INMM fiscal year, it is encouraging to notice that the industry interest in the activities of the Institute continues, as reflected by the constant growth of membership applications and inquiries. New members stand at 69 at this time in early March.

This figure also represents a renewed interest of members of the international nuclear community and recognition of the widespread trend toward the formation of overseas chapters of INMM. New chapters are well under way in both Europe and Japan and recent meetings of the Executive Committee have devoted considerable time and thought to discussions concerning how the Institute can best help and cooperate with the organizing committees of the newly formed chapters.

Closer to home, the membership committee with the help of Journal editor **Tom Gerdis** is updating the INMM brochure and hopes to have the revised edition ready for distribution at the Annual Meeting this coming June.

Despite the larger number of new members received each year by the Institute, we urgently need your help and cooperation in seeking and encouraging more interested and qualified individuals to join your organization. The more active members the Institute acquires, the greater will be the benefit to your own membership and to the nuclear industry.

A larger membership permits a greater participation in the many varied activities of INMM which provide technical help to the industry, such as the preparation of standards, the compilation of highly-acclaimed special reports, for example, the first comprehensive study of the need for safeguards in transportation undertaken by the Institute several years ago and the more recent Special INMM Report developed last year by an ad hoc writing group of the Safeguards Committee, all of which enhance the standing of the Institute and its individual members.

The Institute is not seeking new members purely for the sake of numbers. Your membership committee knows that the most solid base any organization can acquire is a broad membership which has been obtained by the personal efforts of other members. If you sincerely believe in your organization and truly wish to support its activities to the fullest, one of the finest contributions you can make to INMM is to encourage qualified persons to become interested in its work and to urge them to join the Institute.

Your own personal suggestion to a friend who is a potential INMM member is worth more than any 50 letters, invitations, or other exhortations from the membership committee.

Do you need membership application forms, brochures, or the Institute's standard letter of invitation, on which you can write a short personal note of endorsement? Simply drop a note to any person on the membership committee, **Jim Patterson, Vince DeVito, Bob Curl** or **Jim Lee,** or call any of us—your supplies will be furnished promptly. Or, mail us a note addressed to your prospect and we'll add the other documents, attach your note, and forward the invitation directly to your friend—or better yet, friends.

Help your Institute increase its growth with productive new members. Invite a friend to join, or send his name to the membership committee.

DO IT TODAY!

Selection of Meeting Sites

By Raymond E. Lang

Several years ago, **Armand Soucy** established the Annual Meeting Site Selection Committee as a standing committee of the INMM. The purpose of this committee was to put selection of meeting locations on a coordinated and long-range planning basis.

As the meetings have grown in size, the finding and selection of suitable hotel space has required planning two to three years in advance. Our 1978 and 1979 locations are established. We are now doing preliminary planning for the 1980 meeting which will be in the eastern portion of the country.

There are numerous criteria we use in selecting a city and a hotel: 1) We rotate from eastern to central to western locations, 2) We select cities or areas that members and their families will find interesting and enjoyable, 3) We try, but sometimes fail, to find a modern, attractive hotel with adequate and flexible meeting space, 4) We try to select a hotel that will be cost effective for members and their families as well as for the Institute.

The Executive Committee makes the final site and hotel selection, often after having an INMM Executive Committee meeting at the hotel being considered.

We would like to hear your suggestions for future meeting locations, and the annual meeting committee is always looking for local hosts for the meetings.

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Treasurer's Report for Fiscal Year 1976
July 1, 1975 Through June 30, 1976

Cash Balance July 1, 1975:		$ 8,755.99
Receipts:		
Dues	$ 5,591.24	
Journal Income		
Subscriptions	2,642.50	
Advertising	1,618.58	
Proceedings	2,169.00	
Page Charges	2,205.00	
Miscellaneous	771.74	
Annual Meeting		
Registration	14,558.00	
Exhibits	1,070.00	
Miscellaneous	249.00	
Social	1,025.00	
Safeguards School	19,900.00	
Total Receipts:		$51,800.06
Expenditures:		
Journal Editor	$ 4,451.72	
Journal Editor—Travel	1,142.00	
Journal Printing	13,356.36	
Postage	2,862.83	
Telephone	58.85	
Clerical Assistance	794.00	
Miscellaneous	476.68	
Annual Meeting		
Registration	2,185.01	
Meeting	3,744.73	
Hospitality	1,214.54	
Ladies Program	427.51	
Social Event	5,464.37	
Speakers	580.61	
Refunds	215.00	
Miscellaneous	148.19	
Telephone and Postage	478.67	
Stationery and Supplies	272.55	
Executive Committee	836.19	
N-15	86.15	
Safeguards School	18,635.72	
Total Expenditures:		57,431.68
Cash Balance June 30, 1976:		$ 3,124.37
Savings Account July 1, 1975:		14,000.00
Interest Income		1,077.00
Savings Account Balance June 30, 1976		$15,077.00
Net Gain or Loss:		
Total Receipts		$51,800.06
Interest Income		1,077.00
Total Income		$52,877.06
Total Expenditures		57,431.68
Net Loss		$ 4,554.62

Jaech

N15 REPORT

LOOKING FOR WRITERS

By John L. Jaech, Chairman

"Why bother writing standards when NRC Regulatory Guides are being issued independent of the standards writing activities?" This is a question that may explain in large part the slowdown in INMM standards writing that has occurred over the past two years.

In discussing this recently with **Ralph J. Jones,** his reaction is that in view of recent NRC staff decisions, it is even more important **today** to pursue the development of ANSI standards with renewed vigor. This is because future NRC Safeguards Regulatory Guides of a technical nature will largely be limited to endorsing ANSI standards, with possible exceptions noted. The majority of what was formerly Safeguards Regulatory Guides in the NRC Division 5 will now be published as technical reports rather than Regulatory Guides. Thus, this policy decision lays it upon the INMM membership to collectively interpret and expand upon regulations in ways that meet the intent of the regulations but that also lead to meaningful, reasonable, and effective procedures.

Responding to this need for standards represents a challenge, but at the same time, it represents an opportunity to those of you who complain when NRC regulations are interpreted in a way that leads to burdensome and ineffective (in your opinion) procedures. I ask, "Are you ready to seize this opportunity to strike a blow for reasonable safeguards procedures?" If the answer is **yes,** and if you are presently on a writing group, make sure that you are not the one who slows down the group progress. If the answer is **yes** and you are not now on a writing group, call me at (509)-943-8423 and I'll put you to work. If the answer is **no,** then stop complaining about the burden of safeguards imposed by unequal interpretation of the regulations.

On another theme, N15 has two new Subcommittee Chairman within the last few months. **Tom Sellers** is now Chairman of INMM-10, Physical Security, while **John Telford** was recently appointed Chairman of INMM-3, Statistics. This latter appointment was caused by the recent resignation, for personal reasons, of the former Chairman, **Laird Hagie.** A word or two on Laird's contributions to N15 progress over the years are fitting.

It has been my privilege to be associated with Laird on and off over a period of many years, first in the early days at Hanford, then later at Vallecitos, and most recently in my capacity as INMM-3 and N15 Chairman. Over the years I have developed a growing appreciation of his fine qualities. Laird hesitated originally to serve on INMM-3 because he is not a professional statistician and later hesitated to accept the appointment as INMM-3 Chairman for the same reason. However, Laird's contributions are not measured only in terms of technical input to committee work but, more importantly, in his enthusiasm, his eagerness to accept a challenging assignment, his devotion to the task, his unfailing energy, and his unassuming leadership abilities in motivating people of different persuasions to work together toward a common goal. I could cite many instances in which Laird greatly furthered the work of INMM-3, but such citations would only embarrass him. On behalf of the INMM membership, I want to take this means to thank Laird Hagie publicly for his contributions to the development of INMM sponsored standards.

Laird Hagie received his B.S. in Chemical Technology at Iowa State College and served in the U.S. Navy during World War II. He entered the nuclear industry with General Electric in December 1948, Richland, Washington. He became involved with the Nuclear accounting and operation of the reactors as well as the Uranium fuel manufacturing aspects of the business. He was then sent to Advanced Fuel Planning. He transferred to General Electric Vallecitos Plutonium Laboratory, Pleasanton, California in 1965 and helped in the development of advanced plutonium fuel processing methods and computerized accounting procedures. He joined INMM in 1971 and has participated in INMM 15.3 (Statistics sub-committee) since 1974.

Free from NBS

New Brochure Describes NDE

A new brochure describing the Nondestructive Evaluation Program (NDE) at the National Bureau of Standards is now available. The Bureau's NDE program was formed in mid-1975 to assist industry and other government agencies in improving the reliability of materials and structures through standardized NDE measurements.

The role of the NDE program is to help industry develop methods for accurate and reproducible NDE measurements. This includes technical investigations of standards, characterization of instruments, development of improved techniques, and the assessment of the meaning of the NDE measurement on materials performance.

The brochure describes the program's objectives and present technical program; also listed are some NBS publications available on NDE. For a free copy write to Harold Berger, Manager, Nondestructive Evaluation Program, Materials Building A363, National Bureau of Standards, Washington, D.C. 20234.

ERDA Bibliography

To help meet the information needs of scientists and engineers working in energy-related fields, the Energy Research and Development Administration has just published the 1977 edition of **Technical Books and Monographs,** a bibliography of books and monographs sponsored by the Energy Research and Development Administration (ERDA) and by the organizations brought together to form ERDA. This catalog provides access to a large body of knowledge generated by many programs—programs as diverse as the field of nuclear medicine, the exploration of physical mechanisms at work in the environment, and the varied technologies required to realize the potential of the country's energy sources.

Technical Books and Monographs provides a brief descriptive statement, lists or describes the contents for the most recent publications, and indicates the availability. The more than 675 publications are grouped under the following subject categories: general reference, biology and medicine, chemistry, computers and mathematics, energy, engineering and instrumentation, environment, health and safety, isotope separation, metallurgy and materials, physics, reactors, and vacuum technology. Included in the catalog are the titles from monograph series prepared in cooperation with the American Chemical Society, American Industrial Hygiene Association, American Institute of Biological Sciences, American Nuclear Society, and American Society for Metals. In addition to the technical books and monographs, separate sections at the end of each subject category list approximately 175 recent published symposiums from ERDA projects and recent and relevant bibliographies. Title, author, and series indexes are provided.

Technical Books and Monographs is available as TID-4582-R12 without charge from ERDA Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

Annual Meeting Preview

'Safeguarding the Nuclear Fuel Cycle' is Theme of 1977 Annual Meeting in Washington

Keepin

By G. Robert Keepin
INMM Vice Chairman
Los Alamos (N.M.) Scientific Laboratory

The Institute's 1977 Annual Meeting, June 29-July 1, in Washington, D.C. promises to be one of special significance from a number of standpoints: 1) its timeliness in the unfolding debate by the 95th Congress on energy reorganization and the development of a coordinated US energy policy, 2) the strategic location of this year's meeting in the nation's capital, and 3) from the INMM professional standpoint, the technical theme of the 1977 meeting, "Safeguarding the Nuclear Fuel Cycle," is a key issue of major concern not only in the U.S. but in many countries of the world. The emerging thrust of U.S. nuclear energy policy (not yet officially announced at the time of this writing) appears to be a concerted emphasis by the administration on nuclear power generation by light water reactors (LWRs) and, for the time being at least, a sort of "political decoupling" of the **benefits** of LWR power generation from the **problems** (both real and imagined) of spent fuel reprocessing and commercial use of plutonium in the United States. (For example, the much publicized Ford Foundation study on nuclear energy entitled "Nuclear Power, Issues and Choices," carried out by the MITRE corporation was headlined in the April 1 issue of **Science** as "Ford-MITRE Study: Nuclear Power Yes, Plutonium No.") The apparent goal of the administration's approach is to solidify long-term public acceptance of nuclear power in the U.S. by ostensibly separating power generation from the plaguing environmental and safeguards issues which many now seem to view as somehow inextricably linked with plutonium. It's hard to believe that this much-maligned actinide element, which has become so familiar to nuclear materials managers over the years (actually decades), has now fallen into such disfavor. In any case, given the realities of future energy shortages and the enormous latent energy content in spent reactor fuel, there seems little doubt that the recovery of plutonium to fuel safe, safeguarded breeder reactors, and their supporting fuel cycle facilities, will all some day come into their own.

In the meantime, however, if the U.S. is to meet its present responsibilities as a reliable nuclear supplier in an expanding international market, we have little alternative but to expand further our present marginal enrichment capacity in order to fuel the growing number of LWR reactors in the U.S. and customer nations abroad. This will require that greater attention be given to safeguarding the "front end" of the fuel cycle, especially the development and implementation of technically non-intrusive, yet stringent, "perimeter safeguards" for enrichment facilities (both present and advanced technologies), fuel fabrication plants, systems for transport of fabricated fuel to operating reactors, etc.

In addition to providing reliable, safe, and safeguarded front-end fuel cycle services, it is also necessary to provide required services and safeguards at the back end of the LWR fuel cycle. At the very minimum this would involve expanded spent fuel storage capacity—either in a U.S. or an international/multinational facility under effective international (IAEA) safeguards. To illustrate but one example of the role of new technology in implementing effective fuel cycle safeguards, measurement techniques are currently being developed to determine the plutonium content of spent fuel elements during storage in conventional cooling pools awaiting ultimate disposition (reprocessing or permanent storage). Under a suitable buy-back arrangement with the customer, this measurement of plutonium (or latent energy) content could then provide a quantitative basis for crediting the customer's account against the cost of future reload fuel and for assuring that no fuel element substitutions have occurred. If the necessary complex agreements between supplier and customer nations can be worked out, a limited number of international and/or multinational facilities located in key regions of the world could provide full back end fuel cycle services including reprocessing, conversion, mixed oxide fuel fabrication and waste management—all under stringent international safeguards and inspection.

If this inherently international problem is to be addressed effectively, it will be largely up to the U.S. and other nuclear supplier nations to take the lead in developing and implementing effective international (IAEA) safeguards for plutonium facilities—whatever their location or "nationality." And even though we as a nation may temporarily ban LWR spent fuel reprocessing, the major responsibility for leadership in developing and demonstrating effective methods of safeguarding plutonium and associated back end LWR fuel cycle facilities will inevitably reside with the United States, as the world's first and (thus far, at least) foremost supplier of nuclear power reactors.

(Continued on page 36)

14 New Members

The following 14 individuals have been accepted for INMM membership as of April 19, 1977. To each, the INMM Executive Committee extends its welcome and congratulations.

New members not mentioned in this issue will be listed in the Summer 1977 (Vol. VI, No. 2) issue to be sent out in late August or early September.

John A. Beidelman, Management Engineer, Argonne National Laboratory, Bldg. 331, Argonne, IL 60439.

Richard F. Beyer, 206 Navajo Road, Bethel Park, PA 15241.

Eigidio Louis Bellisario, Manager, Nuclear Material Accountability, Babcock & Wilcox Company, NMD, 609 North Warren Avenue, Apollo, PA 15613.

Alan Mark Bieber, Jr., TSO, Bldg. 197, Brookhaven National Laboratory, Upton, Long Island NY 11973.

Albano Ferrer De Moncada, International Atomic Energy Agency, P. O. Box 645, A-1011 Vienna, Austria.

Anthony George Hamlin, U.K. Atomic Energy Authority, Bldg. 10.30, AERE, Harwell, Didcot, Oxfordshire, England.

William W. Henoch, U.S. ERDA, American Embassy, APO San Francisco 96503.

Richard Lee Jaworski, Manager, Reactor and Computer Technical Services, Omaha Public Power District, Omaha, NE 68102.

Frank Edward Jones, Physicist, National Bureau of Standards, 7311 Durbin Terrace, Bethesda, MD 20034.

Kathy Karen Kuta, Junior Engineer, Carolina Power & Light Company, 336 Fayetteville Street, Raleigh, NC 27602.

Alberto Lumetti, International Atomic Energy Agency, P. O. Box 645, A-1011, Vienna, Austria.

John Richard Powers, IEAL, Suite 505, 2600 Virginia Avenue, Washington, DC 20037.

Roy J. Ricci, Intex, Inc., 6935 Wisconsin Avenue, Chevy Chase, MD 20015.

Louis A. Strom, Kirkland & Ellis, 200 East Randolph Drive, Chicago, IL 60601.

Address Changes

The following five changes of address have been received as of April 19, 1977, by the INMM Publications Office at Kansas State University, Manhattan.

Dr. **Curtis G. Chezem,** 3295 River Road, Eugene, Oregon 97404.

Dr. **Francis X. Haas, Jr.,** 7177 Petursdale Court, Boulder, CO 80301.

Tohru Haginoya, Director, Division of Operations B, International Atomic Energy Agency, P.O. Box 590, A-1011 Vienna, Austria.

Emmanuel R. Morgan, c/o International Atomic Energy Agency, P. O. Box 645, A-1011 Vienna, Austria.

Ray Mulkin, 62 Grand Canyon, Los Alamos, NM 87544.

Molen

TECHNICAL PROGRAM REPORT 1977 ANNUAL MEETING

By G.F. Molen, Chairman
INMM Technical Program Committee

The Institute's Eighteenth Annual Meeting will open in Washington, D.C. on Wednesday, June 29, 1977, at Stouffer's National Center Hotel. The meeting will begin with a Plenary Session of prominent invited speakers from government and industry. Our keynote speaker will be the Honorable **Robert W. Fri,** Acting Administrator, U.S. Energy Research and Development Administration. In addition to Mr. Fri we have invited Congressman **Mike McCormack,** the Honorable **Richard T. Kennedy,** Commissioner, U.S. Nuclear Regulatory Commission, Admiral **Harvey E. Lyon,** Director, Division of Safeguards and Security, U.S. Energy Research and Development Administration, and Dr. **Rudolph Rometsch,** Deputy Director General, Department of Safeguards, IAEA.

Mr. **Craig Hosmer,** President of the American Nuclear Energy Council will also be with us for the Plenary Session as will Dr. **L. James Colby,** President, Nuclear Services Division, Allied Chemical Corporation. Both of these gentlemen have been very active in their respective roles of helping mold our nation's future energy policies. Their remarks should be very timely and interesting.

On Thursday, June 30, we will have a luncheon prior to the Panel Discussion on "Safeguarding the Nuclear Fuel Cycle" which is slated for Thursday afternoon. As a very special treat we have invited our own **Bernie Gessiness** of National Lead of Ohio to be Master of Ceremonies for the Awards Presentations. This should be a real treat so do plan to attend the luncheon.

After the luncheon, we will have the Panel Discussion featuring such prominent speakers as Mr. **Raymond Dickeman,** President of Exxon Nuclear Company, Inc., Mr. **R. Gerry Page,** Deputy Director, Division of Safeguards, U.S. Nuclear Regulatory Commission, Admiral **Thomas D. Davies,** Assistant Director, Nonproliferation Technology Bureau, ACDA, Dr. **Rudolph Rometsch,** IAEA, and Dr. **Ed Zebroski,** Director, Systems and Materials, Electric Power Research Institute. After a few preliminary remarks by each of the panelists the discussion will begin with a series of questions from a group of three reporters. Representing the news media will be William Lanouette, National Observer, John Graham, Nuclear News, and Lluewellyn King, Energy Daily. The topic of the panel discussion, **"Safeguarding the Nuclear Fuel Cycle,"** is broad and the questioning will be free-wheeling so that the afternoon should be dynamic, interesting, educational and possibly controversial. Be sure to attend this vital part of this year's program.

A very large number of contributed papers will be presented this year in sessions with themes such as **"Integrated Safeguards Systems," "Physical Protection Systems and Studies," "Materials Control Regulations, and Real-Time Accountability,"** and **"Measurements, Standards, and Calibrations."** Because of the varied interests of those attending the Annual Meeting, we have added a third session for Friday morning and afternoon. This way, attendees will be able to select from a larger number of papers covering a wider variety of subject matter. The program committee realizes that some people may want to attend two sessions at the same time because of the variety but we attempted to structure the sessions such that this problem would be minimized.

Also, this year we anticipate significantly increased foreign attendance and participation. This is attributable in part to the increasing emphasis in many countries on more stringent safeguards because of the mounting concerns on nuclear weapons proliferation.

Since the meeting is scheduled for Wednesday through Friday this year, **the American National Standards Institute (ANSI) committee meetings have been scheduled for Monday and Tuesday, June 27 and 28.**

Finally this year is a year of critical decisions concerning nuclear power for our nation. The challenge to the INMM and its members is clear: the full utilization of nuclear power by this country will depend in large measure on how effectively we are able to convince the public, the Congress, and the White House that plutonium can be adequately safeguarded. Obviously the stakes are high and even though the remaining issues are political and heavily influenced by emotion rather than reason, their importance cannot be underestimated. With this thought in mind the Technical Program Committee has tried to put together a really timely, interesting and informative program. We hope you will agree. So make your plans now to attend the 18th Annual Meeting to be held June 29, 30 and July 1 at Stouffer's National Center Hotel in Washington, D.C. It could be our greatest meeting ever!

Wilson

European Attitudes On Nuclear Proliferation

Professor **Richard Wilson,** of the Department of Physics at Harvard University, gave the first in a new series of seminars in safeguards and proliferation at Brookhaven National Laboratory on March 16, 1977. Sponsored by the Technical Support Organization of BNL, a group that has long worked in this area, the seminars are designed to present the broader issues of safeguards and proliferation.

In his talk entitled "European Attitudes towards Nuclear Proliferation," Prof. Wilson stressed the importance of understanding the points of view of other countries towards nuclear power and proliferation.

He divided the countries of the world into four groups: those who are known to have nuclear weapons, those who could acquire them very quickly (within 1 year) if they decided to, those who could acquire them within five years of a decision, and those who would take longer. The second group includes three countries (Israel, South Africa, and Taiwan) who are suspected to have nuclear weapons already or to be working towards them secretly. Deliberately giving the impression of having nuclear weapons without ever actually confirming or denying it may, he feels, become the trend of the future for beleaguered nations with a credible capability. The remaining countries in this group (Norway, Canada, West Germany, Belgium, Netherlands, Japan, etc.) could easily develop weapons if they chose to but have not. Wilson speculates that the reason is that these countries are satisfied with the status quo. Whatever the reason, U.S. policy must be designed to support and encourage these countries. On the other hand, the countries in the third group (Egypt, Pakistan, Brazil, Argentina, East Germany, and Iran) are not satisfied with the status quo, and must be given incentives not to pursue nuclear weapons.

Prominent scientists and other key figures in the various nuclear energy establishments of Europe whom he interviewed, recently, criticized the U.S. for not restraining one of its "client" states, Israel, from (presumably) developing a bomb while at the same time vigorously protesting the West German and French deals to sell reprocessing plants to Brazil, Pakistan, and South Korea, and the Indian explosion. This inconsistency tends to rob the U.S. anti-proliferation stance of its credibility.

French and German scientists also feel that a nation determined to "go nuclear" is much more likely to do so through isotope separation or the construction of special plutonium production reactors than through the more expensive, conspicuous, and inflexible power reactor. It is estimated that for a small weapons capacity and isotope separations plant would cost about $5 million and a Pu production reactor about $15 million.

Europeans also note that the U.S. has sometimes been less willing to sell reactors to backward countries like Egypt than to sophisticated ones like Israel on the grounds that to do so in the former case would be to spread nuclear knowledge and expertise whereas in the latter case the country already had these!

Measures proposed by the Europeans and Canadians to halt or delay proliferation include more stringent inspection, subjecting the entire nuclear fuel cycle of a country to safeguards, guaranteeing enriched uranium fuel supplies to countries not having reprocessing or enrichment facilities, and giving signatories to the NPT preferred treatment. Prof. Wilson also felt that it was of utmost importance to persuade the French to sign the NPT.

Finally, he urged that someone, somewhere, start thinking hard about the long-term problem of devising policies for a proliferated world.

The next seminar in this series was to be given on April 18 by Dr. **Theodore Taylor,** of Princeton University. The subject will be "Alternate Strategies for Controlling Nuclear Energy: Plutonium, Denatured Fuel Cycles, or Phase-Out."—**Eugene V. Weinstock,** BNL.

Standards Rules

NRC has published two major standards rules within the past few months: (1) An effective rule on the protection of nuclear power reactors against sabotage; (2) A proposed rule for a clearance program for access to special nuclear material. The NRC issued the following press releases on these two rules. _____

The Nuclear Regulatory Commission is amending its regulations to specify detailed requirements for the protection of nuclear power plants against industrial sabotage. Adoption of these measures—to protect the public health and safety—follows an intensive staff review of the entire regulatory approach to safeguards over the past two years.

The new provisions spell out NRC requirements for the physical security organization which must be maintained, including the size of the on-site response force, and for the control of access to and within the nuclear power plant. Other security provisions relate to communications, alarm stations, searches, liaison with local law enforcement authorities, visitor controls, monitored isolation zones around physical barriers, and bullet-resistant construction for vital areas such as central alarm stations and reactor control rooms.

Regulations established in December 1973 require licensees to submit plans for protecting nuclear power plants against sabotage, but those regulations do not specify particular requirements for such plans. Those plans, reviewed and approved by the regulatory staff of the former Atomic Energy Commission and now in effect, include some of the provisions contained in the new amendments.

Proposed requirements were published for public comment in November 1974. Based on comments received and further staff studies carried out in 1975 and 1976, as well as a reassessment of existing security plans and a detailed evaluation of those plans at selected facilities, changes have been made in the rule now being adopted.

One such change is the addition of general performance requirements which define the level of protection required. While no such threats have occurred, the Commission has determined that, both as a matter of prudence and to serve as a basis for judging the adequacy of safeguards systems designs, physical security programs should be able to protect against:

(1) a determined violent external assault, by stealth, or deceptive actions, by several persons who are well-trained (including military training and skills) and dedicated; these persons could have the assistance of a knowledgeable insider and be armed with automatic weapons equipped with silencers; they also could have incapacitating agents and explosives to gain entry or otherwise destroy reactor integrity; and

(2) a threat of an insider in any position, including a guard.

In conforming to these general requirements, the physical security system must meet specific requirements in the areas of security organization (including size of response force), physical barriers, access requirements, alarm systems, and communication testing and maintenance. In addition to several changes in these specific requirements, the new rule clarifies requirements for actions by a qualified guard force and for the nominal size of a well-trained on-site response force.

Licensees must implement requirements concerning security organization, access, communications, and testing and maintenance, as well as the requirements for on-site response force capability, within 90 days of publication in the Federal Register. They also must submit amended security plans for NRC approval within 90 days, and will be required to implement these amended plans as soon as practical after approval; for some measures (for example, those requiring construction), licensees will be given up to a year and a half to comply with all provisions of this amendment. The amendments permit the NRC staff to approve alternatives to the new requirements if they are found to be equally effective in providing protection.

Briefings will be held shortly in several locations to explain the new rules to NRC licensees.

As part of its upgraded safeguards program, the Nuclear Regulatory Commission is proposing to establish a clearance program for individuals working in the commercial nuclear industry who have access to or control over certain quantities of special nuclear material (uranium 233, uranium 235 and plutonium), or access to protected areas of facilities such as nuclear power plants and fuel reprocessing plants.

Two levels of special nuclear material access authorization are proposed. The higher level, NRC-U, would be based upon a full-field background investigation and would apply to (1) all individuals who require unescorted access to special nuclear material or vital areas, (2) personnel in positions which would enable them, acting alone or with others, to divert special nuclear material or to commit sabotage, and (3) drivers of motor vehicles and pilots of aircraft transporting certain quantities of special nuclear material and personnel who escort road, rail, air or sea shipment of special nuclear material. The lower level, NRC-R, would apply to all individuals who require unescorted access within the fenced areas and who are not required to possess an NRC-U special nuclear access authorization. The NRC-R authorization would be based on a national agency check.

Under the proposed clearance program it is the intent of NRC to minimize both the impact on the rights of privacy and association of individuals affected, and the number of persons affected.

The Commission is particularly requesting public comment on the relevance, completeness and suitability of the criteria proposed for use in determining eligibility for access to or control over special nuclear material. The proposed criteria are those now used in NRC in its

personal security program (Part 10 of NRC Regulations). The Commission intends to give careful consideration to this matter, in the light of comments received, in determining the provisions of an effective rule.

The proposed new Part 11 and amendments to Parts 50 and 70 are being published in the Federal Register. Interested persons may submit comments to the Secretary of the Commission, Nuclear Regulatory Commission, Washington, DC 20555, Attention: Docketing and Service Branch, within 60 days. If sufficient interest is shown by comments received, the Commission will give consideration to a public hearing on the matter.

Toy

EDUCATION COMMITTEE REPORTS

By Harley L. Toy, Chairman
INMM Education Committee

You no doubt noted in the past winter issue of the Journal that the Institute is continuing to provide an ongoing educational program by presenting a formal Spring '77 Statistics course in Richland, Washington. This represents somewhat of a departure from our previous course programs that were held at Argonne. We elected to present the course in Richland in order to accommodate the many INMM members in the Tri City area in affording the opportunity to attend the course at a reduced cost. The same holds true for our many West Coast members who expressed an interest in attending the course at a nearby location. At this writing **John Jaech** of Exxon and **Bob Sorenson** of Battelle-Northwest are finalizing plans for the statistics course which will be presented in cooperation with the Joint Center for Graduate Study in Richland. Many thanks are due to John and Bob for their individual efforts in the total planning and negotiations for our first regional educational program.

Your Education Committee looks at the Richland program as the springboard for launching an expanded comprehensive educational program that will respond to the timely needs of the membership. The Education Committee is most fortunate this year in obtaining top flight members to guide the Institute's program. On board are **Manny Kanter** of Argonne who has all the credentials in the education area, and Dr. **Frank O-Hara** of The Ohio State University currently teaching in the Nuclear Engineering Department. Rounding out our group are **Jim Patterson** of NRC's Region III, **Bob Sorenson** of Battelle-Northwest, and **Dick Chanda,** Atomics International at Rocky Flats. Also providing sound input and counsel are **Vince DeVito** of Goodyear and **Bernie Gessiness** of NLO.

Our committee has outlined several areas where we feel the Institute could be effective in staging educational programs that would best meet the needs of the membership. Our overall objective is to promote and implement an overall broad spectrum educational program which would include:

- Formal course programs.
- Seminars or workshops in conjunction with annual meetings (Dick Chanda's thoughts).
- Regional topical meetings.
- Provide a clearinghouse function on educational programs being offered.

These items were discussed in detail at the INMM Executive Committee Meeting in February in Washington. In discussing formal course programs, we advised that offers have been received from three or four organizations willing to provide space and facilities for conducting INMM sponsored courses. The National Bureau of Standards, Oak Ridge National Laboratory, and Battelle's Columbus Laboratories are among those organizations interested in hosting courses.

Chairman **Roy Cardwell** has developed an outline for a proposed Guard Force Supervisor Course which would be presented at Oak Ridge under co-sponsorship of INMM and ERDA-ORO. Roy advised that the details are still under study. The specific curriculum would address "Nuclear Plant Protection Supervision" relative to implementation of ERDA Manual Chapters and 10CFR Part 73. Assisting Roy in the proposed formal training course are **Howard Rosser,** Chief, Physical Security and **J. S. Denton,** Deputy Director of Security, both of Oak Ridge Operations. We are all aware of the current emphasis on physical protection in Safeguards and recognize the pressing need for formalized training in this area. This is presently the Education Committee's number one priority, that is, to get this course on line. We are aiming for late summer to be in a position to proceed with the Guard Force Supervision Course.

In the coming weeks, we plan to meet with ERDA and NRC officials to discuss the active INMM role in safeguards training and explore areas of mutual cooperation. **Manny Kanter** is actively engaged in all phases of safeguards training and is following closely the international scene in safeguards education.

The clearinghouse service function of alerting our members to training course announcments will begin in the next issue of the Journal. At the annual meeting in June, we will provide a status report on all educational activities and evaluate our efforts to date. Other ongoing educational activities includes close liaison with Dr. **Fred Forscher** relative to the INMM Certification Program. Even though it appears that a professional certification program sponsored by INMM is somewhat down the road, we must plan now to meet the educational requirements such a program will demand.

One closing thought that occurred to me during the past Executive Committee Meeting and that is that Chairman Cardwell and the Executive Committee are strongly committed to all-out support of a viable INMM Education Program. One of their main concerns and top priorities is meaningful service to the membership through an effective and timely education program. They are proud of the past results of the educational program presented at the Argonne Center and look to increased emphasis in the area of training and education.

Energy Management

By Dr. Frederick Forscher

An energy policy, or any part of it, must be based on acceptable and credible decisions. In our consensual democracy, acceptable and credible decisions are arrived at by an open process of public participation. If this process seems slow and inefficient, it is the price we have to pay for credibility and acceptability; it distinguishes our system from more direct and autocratic decision making.

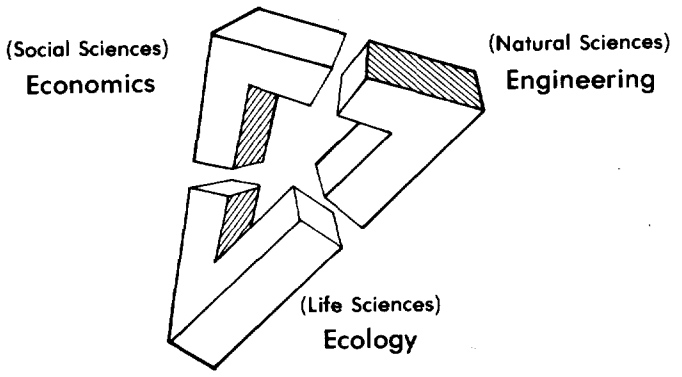
In this context, a "public" decision will be made when the perceived benefits exceed the perceived risks. "Perceived" risks and benefits are those which the public, by virtue of their own knowledge, experience and beliefs, view as real. Energy management can contribute importantly to this decision making process.

PRINCIPLES OF ENERGY MANAGEMENT

1. Energy Management is a **new profession,** combining the disciplines of engineering, economics and environmental sciences. Energy management is bound to become an important specialty in management consulting, and later in corporate management itself.

2. Energy considerations must be included in **every planning** function, be it economic, industrial, social, regional or national; by any agency, department or corporate cost center. Every business decision is affected by the availability and price of energy. The more energy intensive the product or service, the more should be invested in the planning and management of energy.

3. Energy management is a useful **managment tool,** leading to better profitability and higher reliability of products and services. Business will have to learn how to manage its energy resources, as it learned to manage labor, materials, and financial resources. Many companies have ongoing energy **conservation programs,** directed by consultants and selected in-house staff. While this is an important first step, these programs usually do not take into account the environmental, societal, and macro-economic effects of energy management.



4. **Resource recovery** is a desirable goal of energy conservation. The dilemma of the energy situation is that energy is needed to recycle any of the material resources, but **energy, itself, cannot be recycled.** The present awareness of society-energy inter-relation has not yet reached the point where the simple physical truth that energy (like time) cannot be recycled is recognized as the second law of **thermodynamics,** and associated with the order-disorder concept of the second law.

5. What we need is a **new methodology,** a new frame of reference, within which all informed and concerned parties can attempt to resolve the energy issues. Whatever the new methodology, its application ought to lead to less waste. In thermodynamic terms, less waste means "more order," less entropy. Less waste means also less freedom of choice and less freedom of action, which is bound to stir some complaints.

6. Fuels are related to energy, like food is related to calories. The processes by which society "digests it's energy diet" can be described as **Social Metabolism.** We must begin to recognize the significance of this difference between fuels and energy, and make a concentrated effort to unravel the pathways of social metabolism.

7. The energy issue is not merely an economic issue, or a technological issue, or even an environmental issue, but a **holistic issue** involving *all* the branches of knowledge. It has been said that human history is a race between knowledge and disaster. With a new understanding of social metabolism we may yet be able to avert the disaster. Energy, being a common denominator in all fields of knowledge, should be a unifying concept, rather than being divisive.

8. Knowledge per se is sterile. When knowledge from the three branches of science is **applied** to the real world of energy, some incompatibilities become apparent that this illusionary triangle attempts to illustrate. While each corner of this triangle seems to address the other two corners in proper fashion, the three corner pieces just don't fit reality.

9. The public must develop a better awareness and understanding of the energy issues, and **form a constituency** like the environmental movement, anti-war, women lib, civil rights, etc. Blaming the Arabs, or the oil companies, or Congress, or environmentalists for our failures is divisive and counter-productive.

Taylor's Alternative Strategies

In the second seminar on safeguards and proliferation sponsored by the Technical Support Organization of Brookhaven National Laboratory and given on April 18, Dr. **Theodore B. Taylor** of Princeton University set the safeguards problem in the broader context of world energy needs in the next fifty years. His talk, entitled "Alternative Strategies for Controlling Nuclear Energy: Plutonium, Denatured Fuel Cycles, or Phaseout," ranged from the development of new, safeguardable fuel cycles to the effects of vastly increased burning of coal on the atmosphere.

The next ten or fifteen years, he feels, will be the most critical in human history, for during this period fundamental decisions on how to provide sufficient food and energy for a rapidly expanding world population will have to be made. By the year 2025 the world population will be about eight billion. If the people living in what are now the less developed countries are to achieve by then a standard of living equal to even one half that in the U.S., a six-fold increase in energy will be required. If this increase were to come from the burning of coal, the amount of carbon dioxide in the atmosphere would more than double, and would increase at the rate of 4-5% per year. The result would most likely be drastic changes in world heat patterns and precipitation. It would thus appear that coal is not the long-term solution.

If half the needed energy came from fast breeders, a total of 10,000 1000-MWe breeders would be required by the year 2025. These would be supported by 200 reprocessing plants the size of Barnwell, which would ship 10,000-15,000 Te of Pu per year to fabrication plants. Thus, roughly a million weapons' worth of plutonium would be shipped over the roads annually. Although it is possible to design a safeguards system against criminals at a cost of less than 2% of the total cost of power, it is not at all certain that all the countries involved would actually be willing to adopt the necessary measures. Also, with such huge quantities of plutonium it is hard to see how a spillover into military use could be avoided.

A fourth alternative is solar power. If a combined collection and conversion efficiency of 10% can be achieved, a total collector area of 1% of the land area of the world could supply all the energy needs in the year 2025. If care was taken to avoid areas of high albedo, the effects on the environment would be small, although the direct costs might be high. In the next five years it may be possible to describe how the world could "go solar" by 2025. Technical and economic developments in the past year have been particularly encouraging. It is important to realize that economies of scale for solar power peak not at 1000 MW, as for nuclear, but at about 20MW—that is, for systems sized for 100-1000 houses. Storage for such systems becomes much more practical than for individual houses. Other possibilities exist for the efficient conversion of solar power, for heating, air conditioning and electricity.

It is inescapable that any country that wants to make nuclear weapons can do so. Almost any country has enough uranium to fuel a graphite or D_2O-moderated reactor. Enrichment is also becoming simpler. However, it is also possible to "drift" towards nuclear weapons. The plutonium fuel cycle would automatically present a country with material from which a weapon could be made even though the country made no conscious decision to obtain material for nuclear weapons. This is an example of what has been termed "latent proliferation." Very serious consideration should therefore be given to possible alternatives to a worldwide plutonium fuel cycle.

One possible alternative is a fuel cycle based on U^{233} and thorium. U^{233} has the advantage, from a safeguards standpoint, that it can be "denatured" with U^{238} so that it could not be used for nuclear weapons without further enrichment. It can breed at thermal energies, which U^{235} and Pu^{239} cannot, and, in the actual energy spectrum of present fast breeders, is approximately as good as Pu^{239} (although not as good at fission-spectrum energies). CANDU's can probably be made to breed with U^{233}-Th fuel. A fuel mixture containing U^{233}, U^{238}, and thorium in the proportions 1:8:(20-30), respectively, could be used for light water reactors, while proportions of 1:8:(70-80) could be used in heavy water reactors; in neither case would the uranium be at a high enough U^{233} enrichment to be usable in practical nuclear explosives. Plutonium production in such reactors would be about 1/10 as large in LWR's and 1/30 as large in HWR's as at present. To get the initial U^{233}, reactors fueled with plutonium or 20% enriched uranium and thorium would be required. These could be located in special heavily safeguarded energy centers, along with reprocessing and fabrication plants. The latter would fabricate denatured U^{233}-U^{238} fuels for LWR's and HWR's outside the centers, and U^{233}-Th fuels for the breeder reactors.

It will probably take about 10 years to sort out the various alternatives the the Pu-U breeder economy. If a decision were made in 1987, LWR's and HWR's then under construction would be completed, but gradually, probably beginning in the early 1990's, reactors using the new type of fuel would be phased in, replacing the older types.

It therefore appears that fission reactors will be with us for at least another 30 or 40 years. It would have very serious effects on the economy if the very large investment of captial in these plants were simply discarded. However, delaying the breeder for ten more years would not disastrously affect the supply of uranium. Studies at Princeton suggest a maximum of 250 GWe of installed nuclear capacity by the year 2000. Uranium reserves recoverable at \$30-50/lb are about 3×10^6 tons although a recent study claims half of this amount. There is no possibility that world uranium reserves could be exhausted before 2015-2020. If the present encouraging signs hold up, this would allow adequate time for the development of solar as a major energy source.

Talk summarized by **E.V. Weinstock** and **J.R. Lemley**, of Brookhaven National Laboratory

Participants in the INMM Statistics Course March 28-April 21 at the Joint Center for Graduate Study, Richland, Wash., heard John Jaech of Exxon Nuclear teach on "Selected Topics in Statistical Methods for SNM Control."

Among those who took Mr. Jaech's course at Richland were (left to right) George Furner, ARCHO; Rich Hamilton, ARCHO; Al Walker, ERDA/RL; and Jerry Hamada, NRC/Region V. There were 19 other participants in the joint JCGS/INMM course.

Successful INMM Course

By Robert J. Sorenson
Battelle Northwest

In response to a number of local requests, **John L. Jaech** presented his course entitled "Selected Topics in Statistical Methods for Special Nuclear Material Control" at the Joint Center for Graduate Study (JCGS) in Richland, Washington, during the week of March 28-April 1, 1977. The course described a variety of statistical techniques which can be used to treat the problems encountered in nuclear materials control. Special emphasis was given to calculating the uncertainties of safeguards indices, estimating errors of measurement, and the difficulties in quantifying the inspection function. Mr. Jaech has previously presented a similar course at Argonne and NRC-Bethesda.

The course was jointly sponsored by the Institute of Nuclear Materials Management and the Joint Center for Graduate Study. As can be seen from the photographs, the JCGS was an ideal place to hold the classes. These facilities are very comfortable with an environment conducive to classroom work. In addition, the weather cooperated and it was a lovely week in Richland for the out-of-town people.

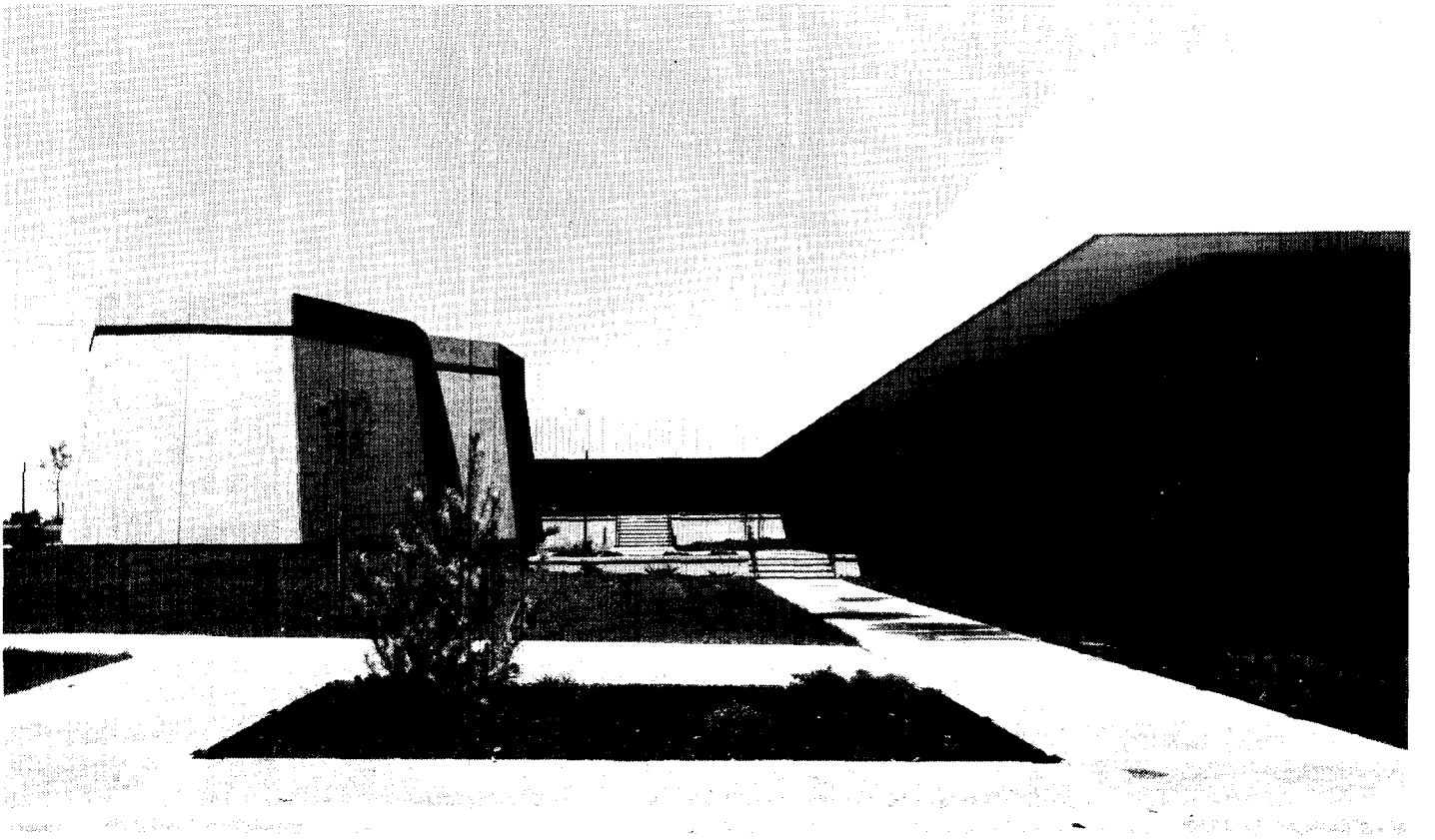
The course was attended by 23 persons primarily from the Tri-Cities area, but two people came from as far away as Washington, D.C. The local attendees represented: Atlantic Richfield Hanford Company, Westinghouse Hanford Company, Battelle-Northwest, United Nuclear Industries, Exxon Nuclear, and ERDA-RL. Those out-of-town participants were: two from NRC Headquarters, one from NRC Region V, and a graduate student from the University of Washington in Seattle. As usual, Mr. Jaech did a great job in presenting ideas and concepts which are difficult to understand (no one failed the course!). A number of comments from the students confirmed what a good job he really did.

Unfortunately, the number of attendees was limited and eight people who had submitted applications were unable to attend. However, Mr. Jaech felt that going beyond 16 would tend to limit discussion which he believes is very important to a successful class. We did, however, ratchet him up to the classroom capacity. He plans to offer the course again at the JCGS during the Fall of 1977. The eight people are on a waiting list and others interested in attending should contact **Jo Ann Hass** at the JCGS at (509) 943-3176. —**Bob Sorenson.**

Visiting informally between sessions with Mr. Jaech (left) are (from left) Dale Oden, Battelle; Ken Byers, ARCHO; Marv Schnaible, Exxon; Tony Kraft, Exxon; and Bob Sorenson, Battelle.

Another roundtable discussion during the INMM course included (from left) Craig Timmerman, Battelle; Bill Russell and Pete Keenan, WHC; Clark Harvey, Battelle; and Don Thurman, NRC Headquarters.

Participants in Spring 1977
JCGS/INMM Course



Joint Center for Graduate Study
Richland, Washington

Book Review

Radioactive Waste Management

Campbell

High-Level Radioactive Waste Management, Editor: Milton H. Campbell, Exxon Nuclear Co., Inc., ACS-1976.

High-Level Radioactive Waste Management is taken from the proceedings of an American Chemical Society meeting sponsored by ACS's Division of Nuclear Chemistry. The meeting, held April 1-2, 1974, was meant to provide an overview of radioactive waste management.

This volume can be divided into several natural subdivisions of the overall topic. First, the Energy Research and Development Administration's (ERDA) philosophy and policy are covered in four papers beginning with **Frank Pittman's** paper describing the current approach generally taken by ERDA and the general outlook for the future. The three papers following describe how wastes are being handled at sites where they have been generated in support of ERDA programs. All three of these papers present, in considerable detail, the programs being pursued at the ERDA sites to deal effectively with radioactive wastes.

Two papers address the problems encountered in waste management plans for commercial reprocessing plants.

There are a number of papers which deal with how the long term problems of radioactive waste management have been approached. Two papers, from Oak Ridge National Laboratory and Battelle Pacific Northwest Laboratories, describe conceptual and practical approaches to radioactive waste management. Several more specific papers present topical discussions of significant individual investigations. The general overview is completed by a paper describing European waste management practices.

The general level of this book requires some prior knowledge of the waste management issue. The object of the book is clearly not that of reassuring the reader that the best solutions have been recognized and are being implemented. Rather, the intent is to report responsibly to professional scientists familiar with the waste management issue, describing what options actually exist and the current state-of-the-art with regard to those options.

The book is invaluable as a tool for the professional striving to understand the scientific issues and possible solutions in radioactive waste management. Societal and peripheral issues, such as the economics, administration and security of waste depositories, are not covered and they were not meant to be. The problem of waste management is approached as a problem unattached to other considerations such as the nuclear power debate or proliferation. While this approach may not satisfy the individual who is seeking a broad understanding of the radioactive waste issue, the book is a collection of exceptionally well written scientific papers describing in detail how a task of great technological importance is being dealt with on a practical level.—**John N. O'Brien,** Brookhaven National Laboratory.

Book Review

Behavior of Actinides

Actinides in the Environment, Ed. Arnold M. Friedman, ACS Symposium Series 35, Washington, D.C., 1976.

A very informative—even if rather short, monograph. The authors have in a concise manner described the present status of the environmental behavior of actinides by drawing attention to the essential parameters, problems and solutions associated with the environmental behavior of actinides. The presentations are cross-referenced with key references, which should be consulted for details. The topics deal with waste management, from repository systems to degradation and subsequent geological and biosphere transport. The need for site-specific modeling is emphasized. Based on field, laboratory and modeling data, the bulk of actinides (e.g. Pu and Am) remains found in some forms to the matrix where it is deposited. However, there is a fraction of the total that does migrate in the environment. Once in the environment, a number of pathways are possible. The environmental transport depends on the chemical form of the actinides as well as on local geographical and geological conditions. Brief mention is made of bioaccumulators, indicating for example, that plutonium levels in marine invertebrates on the whole are higher than in marine vertebrates. Such bioaccumulations are of obvious importance in food chain studies. Two potential pathways of actinide transfer from marine environments to man involve consumption of seaweed and fish protein concentrate. Pu (VI), a soluble species of plutonium may be associated with its mobility in the environment. It is also suggested that more information is needed on the magnitudes of uptake of non-plutonium actinides by biological organisms. In terms of long term consequences of plutonium release, a better understanding of the mechanisms, species and rates of transfer is needed for proper evaluation of real or imaginary hazards associated with plutonium and other actinides. In terms of long-term geological storage, the study of a natural fission reactor discovered in Gabon, Africa is especially worthwhile.

It is the opinion of this reviewer that such monographs should be updated and published from time to time as our understanding of the behavior of actinides in the environment becomes progressively more sophisticated.—**E. Premuzic,** Brookhaven National Laboratory.

FUSION REACTIONS PRODUCED

LOS ALAMOS, N.M.—Scientists for the first time have successfully used a carbon-dioxide (CO_2) laser system to produce a fusion reaction. Labeled a milestone, the achievement was reported by researchers at the Los Alamos (N.M.) Scientific Laboratory (LASL), who used the world's largest CO_2 laser system to induce thermonuclear reactions in microscopic fuel targets.

The experiment, according to Dr. **Gene McCall,** alternate division head of LASL's Laser Research and Technology Division, "presents the possibility that the CO_2 laser may indeed be the laser of choice for future laser-fusion power reactors."

Dr. **Sidney Singer,** chief of LASL's CO_2 Laser Systems Development Group, explains the significance of the event by saying, "It clears away an obstacle in deployment of carbon-dioxide lasers for fusion energy production."

The ideal fusion reactor laser system should have 3 essential elements, he explains. It must be efficient, it must have a high repetition rate, and, as it had been thought, it must have a short wavelength so that most of the laser's power is deposited close to the fuel pellet target for maximum effect. In addition, any such laser must be capable of being "scaled up" in size, to produce the huge amounts of energy needed for useful laser fusion.

Dr. Singer says the carbon dioxide laser has long been known to have 2 of the 3 essential elements. It has efficiency and a high repetition rate. In addition, he says, there are no realistic limits to the size of CO_2 systems. However, the carbon-dioxide wavelength, which is in the middle infrared segment of the spectrum (at 10 micrometers), has appeared undersirable, compared with the other leading contender for a fusion reactor system, the neodymium glass (Nd) laser.

"The glass laser operates at 1 micron, but it lacks the efficiency of the CO_2 laser and it also lacks the high repetitive capacity essential to sustained fusion reactions for power generation," Dr. Singer says.

"Now that we have induced fusion reactions in pellets using a CO_2 system, we have confirmed our contention that the comparatively long wavelength of this laser does not present a problem."

LASL's major effort in laser development has been in carbon dioxide systems, although some work has been done in both Nd and chemical lasers.

Dr. McCall says, "The success of the experiment was made possible by more than 5 years of concentrated theoretical and experimental work carried out by all of the groups in the Laboratory's Laser Research Division."

Dr. Singer sums up the recent achievement by saying, "A series of experiments which began in October, 1976, when the two-beam CO_2 laser under development at the Laboratory was first used for target interaction, culminated in the detection of an unmistakable flux of 14-MeV (million-electron-volt) neutrons that are characteristic of thermonuclear processes (fusion reactions)."

Both scientists say that LASL researchers have long believed that wavelength was not an insurmountable obstacle to the achievement of fusion reactions.

"Our data implies that where the laser energy is deposited in relation to the target is not the limiting factor that it was theorized to be," they say.

A thermonuclear reaction was achieved when the 2 beams that comprise LASL's carbon-dioxide laser system each delivered about 200 joules of energy in 1 nanosecond (a billionth of a second) to a spherical target filled with deuterium-tritium (heavy isotopes of hydrogen) fuel. A joule is a unit of energy, specifically, 1 watt of energy delivered in 1 second. Dr. Singer says the LASL system will ultimately be capable of delivering up to 900 joules of energy, possibly within a year.

Development of CO_2 laser systems at LASL began in 1970, expanding a small program in existence since 1963. The two-beam system with which fusion reactions were obtained is part of an integrated program involving development of an eight-beam system which is scheduled for completion in 1978, and the construction of a High Energy Gas Laser Facility (HEGLF), where it is hoped "scientific breakeven" fusion can be demonstrated. Breakeven is that point at which the energy extracted from fusion reactions is equal to the energy it took to produce them.

The HEGLF is now in the design stage. Construction should begin later this year, with completion scheduled in 1981.

The ramifications of the LASL achievement are important, McCall and Singer stress. McCall says, "For current lasers of a given power output (watts of energy delivered to a target), the CO_2 is more than 10 times as efficient as a neodymium glass laser at about one fourth the cost."

Dr. Singer adds, "The technology of the carbon-dioxide system is the most attractive of existing ultrahigh-energy systems, and although there are practical limits to scaling them up to the size needed for a fusion reactor, we feel we are well within these boundaries in the systems under development at LASL."

The researchers say the two-beam fusion demonstration may "lop 10 or even 20 years from the generally accepted time required for development of a fusion reactor (usually placed early in the next century), and ultimately result in a considerable dollar saving."

A laser system for a typical 1000-megawatt electrical generating plant would probably have to deliver as much as one million joules of light energy on target in less than 1 nanosecond. Repetitive firing of laser beams in rapid sequence, to deliver precise amounts of light energy on a succession of tiny deuterium-tritium fuel pellets, is the method most researchers envision for fusion reactors of the future.

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CLANDESTINE ENRICHMENT OF LOW-ENRICHED URANIUM BY SUB-NATIONAL GROUPS: A PERSPECTIVE

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1.0 INTRODUCTION

At least for the next few years, uranium will remain as the dominant fuel used in the nuclear power industry. Natural uranium contains a very low concentration of fissionable isotope, U-235, limiting its usefulness as an energy source. However, more useful uranium fuel can be produced from natural uranium by using enriching processes to increase the U-235 content. At low enrichments, uranium becomes useful as fuel for light water reactors, while at very high enrichments it can be used in other applications, including nuclear weapons.

A recently published Institute of Nuclear Materials Management (INMM) report[1] provided an assessment of domestic safeguards risks associated with low-enriched uranium (INMM-LEU Study). This study discusses the threat associated with the use of low-enriched uranium in toxicity, criticality, and nuclear-explosives events. However, an important ancillary concern addressed in this study is the threat of a domestic adversary upgrading clandestinely acquired low-enriched uranium using a covert enrichment process. This current paper reviews information compiled on this subject in support of the INMM-LEU Study and presents a discussion of the available processes and the technical difficulties associated with establishing even the most rudimentary sub-national separative capability.

It is highly significant to note that the INMM report[1] and this perspective address only potential domestic subnational levels of clandestine operation. International questions and those relating to national levels of support for such operations are not considered.

2.0 BACKGROUND

Uranium enrichment is the process of concentrating the fissile isotope Uranium-235 in a portion of uranium supply by depleting its concentration in other portions. It is a highly technical process which requires specialized facilities which have been attained heretofore only as a result of a national-level scale of effort.

Most knowledgeable experts conclude that the successful illicit upgrading of low-enriched material by a subnational group to provide weapons material is highly unlikely. For example, some sources (2,3) have stated that if a private interest or foreign national group seriously wanted to obtain either weapons-grade material or material that could be upgraded to weapons-grade, it would be more practical and likely to consider obtaining plutonium or fully enriched uranium than it would be to divert low-enriched uranium for use as feed to an enrichment facility. Further, if such a perpetrator had the technical and financial capability to construct a facility for upgrading low-enriched uranium to a form usable for explosive devices, then he also would have the capability to produce such materials from natural uranium which is much more readily available. Still another source (4) has stated that in any clandestine scheme it is difficult to ascribe a serious diversionary risk to low-enriched uranium facilities, and it seems highly improbable that anyone sufficiently sophisticated to develop both enrichment and nuclear-explosive fabrication capabilities would be naive enough to base his scheme on the ability to steal feed stock from a facility licensed for the possession of low-enriched uranium.

Even though recent safeguards studies (5,6) have again described the low strategic value and lessened safeguards implications of low-enriched uranium, some observers (7) remain concerned that a clandestine enrichment operation may be credible. Therefore, the following discussion addresses the technical significance of the threat of clandestinely upgrading the enrichment of uranium.

3.0 OVERVIEW

In order to adequately address the feasibility of a subnational clandestine group establishing an enrichment capability which might be capable of producing sufficient nuclear material to bring about some maleficent objective, numerous factors must be considered. For example, a major characteristic of all uranium enrichment processes, presently available or currently anticipated, is that they are highly technical, highly protected (classified), and highly capital intensive. Thus to demonstrate even the most primitive enrichment capability, monumental investment would be required in technology, energy, facilities, technical and operating staff, and uranium inventory.

All of the present nonexperimental domestic uranium enrichment facilities are based on the gaseous

diffusion process. Future domestic plants may use other methods such as gas centrifuge or laser processes currently under development which could permit future plants to be somewhat smaller, yet economically competitive. However, it is significant to note that such advanced processes are currently in the development and pilot stages, and most are years away from implementation (8,9). Further, none of the processes lend themselves to a scale which could facilitate a possible subnational clandestine enrichment operation.

Low-enriched uranium is more useful as a feed for any enrichment process (per unit of available separative work) than is natural uranium. However, to take advantage of this factor, a clandestine group must possess sufficient capital, technical, and operating resources to establish a significant separative work capability. The relative scale and feasibility of a clandestine group establishing such a capability is best demonstrated in an example. The commercial production of 90 weight percent U-235 from natural uranium (0.71% U-235) requires a massive facility with over 3,000 gaseous diffusion stages in series (10). A plant constructed for the purpose of producing nuclear material of up to 4.0% U-235, as might be required for typical LWR's, would contain approximately 1200 stages. A recent study (11) has estimated that the capital costs of a facility capable of producing even one explosive device a year would be on the order of 25 to 50 million dollars, depending on the processes selected. It is totally inconceivable that a domestic clandestine group could establish even a small fraction of such a capability.

Based on these analyses, it is clear that programs for achieving a maleficent objective which are based on long lead times, high technical uncertainties, and no backup options associated with clandestine enrichment clearly expose a subnational group to a high risk of detection or failure. Accordingly, it is quite unlikely that this approach would be selected compared to other alternatives with higher probabilities of success (e.g., theft of a weapon, or plutonium or fully enriched uranium). Further, it is equally unlikely that the enrichment approach could be successfully utilized by a group to achieve its maleficent purposes.

4.0 ENRICHMENT CAPABILITY

In evaluating the incentive for clandestinely enriching low-enriched uranium, it is important to evaluate three basic features associated with uranium enrichment potential and processes. First, the relative advantage associated with low-enriched uranium compared to natural uranium; second, the technical feasibility of establishing even the smallest separative work (SW) capability capable of eventually producing sufficient enriched uranium to support clandestine objectives; and third, the relative safeguards risks associated with key components of the processes necessary to establish enrichment capability. These topics were addressed in the INMM LEU Study, and are further defined in the following discussion.

It is frequently held (7) that low-enriched uranium could be easily enriched to a form usable for a nuclear explosive, or other maleficent activity. For example, one author (11) has stated:

"Although slightly enriched uranium used in the U.S.-developed light water reactors (2 to 4 percent uranium-235) cannot itself be used as a nuclear explosive, it can be upgraded for that use with relatively little effort. Indeed, the amount of highly enriched uranium that could be produced in a given time by an enrichment facility, say, a small gas centrifuge facility, can be sharply increased, typically by a factor of five or more, if the feed material is slightly enriched uranium instead of natural uranium."

Although this statement is basically true, it is important to understand the specific framework and limits for which it was intended. Specifically, it was considering a foreign or domestic national level effort that would be needed to provide a facility capable of more than 50,000 kg of separative work per year; this separative work capability was considered "very small" (11) by comparison with the separative work available from the U.S. gaseous diffusion complex which has an approximate capacity of 17,000,000 kg SW per year (10).

A facility capable of 50,000 kg SW per year is about the size that has been considered for small prototype legitimate plants in the Netherlands and the United Kingdom. Under the conditions cited, a plant of this type could produce enough slightly enriched uranium per year to refuel a 350-megawatt reactor. If reconfigured, it would also produce about 200 to 350 kilograms of 90% U-235 per year. In rough terms, this is equivalent to the nuclear material requirements for 10 to 20 nuclear-explosive devices per year. However, under the conditions that could be practically achieved by a small clandestine group, the feasibility of making even one device a year is vastly smaller.

For example, based on the current technology, a clandestine subnational enrichment operation would most probably consist of a series of gas centrifuges roughly like those under development today in Europe (each rated at 5 kg separative work per year). In this case, it would take 10,000 such machines to produce the same quantity of enriched uranium as the postulated foreign prototype facility discussed above (e.g., 50,000 kg SW/year). Assuming a maximum of about twenty centrifuges could somehow be obtained by a clandestine group without detection (such equipment is not currently commercially available anywhere), then a capacity of about 100 kg separative work per year might be established. This compares to 50,000 kg SW per year postulated for a small national-level-of-effort facility, a factor of about 500 lower. Such a very small capacity would allow the clandestine manufacture of less than 0.02 to 0.04 device (using 90% U-235) per year, using natural uranium as feed, or one device each 30 to 50 years. Using typical low-enriched uranium as a feed, it would take 6 to 7 years to produce sufficient nuclear material for one nuclear device. Clearly, this is not a credible schedule.

An example of the technological and inventory resources necessary to establish a significant enrichment capability is shown in the following table where the separative work and feed requirements to produce 20 kg of 90% U-235 based on the diffusion process are given in Table 1(11).

TABLE 1

Feed Isotopic Concentration	Waste Isotopic Concentration	Separative Work Required (kg SW)	Feed Required (kg)
4.0	3.0	560	1,740
4.0	2.0	680	880
2.0	1.0	1,300	1,780
0.711[a]	0.6	2,840	16,000
0.711[a]	0.2[b]	4,540	3,520

[a]*Uranium-235 concentration in natural uranium*

[b]Standard waste concentration for U.S. gaseous diffusion plants

The effects of feed enrichment and waste composition on the separative work and feed requirements are highly significant. For example, relative to the standard calculation of separative work requirements to produce weapons-grade materials (e.g., feed enrichment = 0.71% U-235, waste enrichment = 0.2% U-235), the use of light water-reactor-grade enriched uranium as feed can reduce separative work requirements to about 15 to 30 percent of the normal requirements. This, in turn, means that under certain conditions the actual capability of a small enrichment plant to produce weapons-grade materials can be a factor of from 3 to 7 greater than its nominal capability. However, this advantage is entirely predicated on the availability of an ongoing facility capable of 50,000 kg SW per year. Assuming the credible clandestine capacity would be less than 100 kg SW per year, even if ample 4.0% U-235 feed were available, which is highly unlikely, it would take almost six years to produce enough fully enriched uranium for one nuclear-explosive device.

It is clear that the technical, energy, inventory, and facilities requirements necessary to establish such a complex technology (i.e., a gaseous diffusion capability) could not be sustained on a subnational level. Even with the availability of shorter term enrichment alternatives (i.e., centrifuge or nozzle processes), feasibility on a scale to result in the production of sufficient U-235 on a reasonable time schedule is not credible. Finally, although theoretical work in laser technology indicates it may prove feasible, the industry is years away from establishing a workable process.

A more detailed discussion of process capabilities and limits associated with current or projected enrichment processes is provided in the Appendix.

5.0 CONCLUSION

One of the basic conclusions of the INMM-LEU Study was that the risks to the public health and safety and to the common defense and security of the United States from the maleficent use of illicitly acquired low-enriched uranium (less than 20% U-235) are insignificant. The only threat perceived was the uncontrolled export of low-enriched uranium to a foreign nation with enrichment or conversion capability. It was further concluded that current trends toward the increasing regulation of special nuclear material have increased controls for low-enriched uranium beyond a reasonable need in view of the relative low risks involved. In this regard, the risks from low-enriched uranium are more closely related to those from natural uranium than those from fully enriched uranium. Therefore, changes should be made in the level of safeguards requirements for this material to bring it to a level commensurate with the risks.

These conclusions are supported by the additional conclusion that the risks associated with the use of low-enriched uranium as a feed material for a domestic clandestine enrichment facility and the subsequent use of the enriched uranium produced are insignificant. These risks were evaluated to be not significantly different from the analogous risks associated with natural uranium.

This conclusion resulted from the consideration of a number of factors. Currently available or projected future heavy isotopes enrichment processes are so highly technical and complex that it is considered extremely unlikely that a clandestine enrichment operation could be successfully conducted without detection, even at the minimum level necessary to produce material for one device per year. No subnational clandestine group could credibly accumulate the resources necessary to establish even a rudimentary enrichment capability. The technologies associated with enrichment processes are both sophisticated and highly protected (classified) and have resulted from years of intensive research and development. Further, future innovations do not appear capable of significantly reducing these technological requirements. In any case, the financial resources and technical staff necessary to establish and operate such a facility is most likely well beyond the capabilities of a subnational group. It would be unrealistic to propose that any subnational group would attempt to accumulate the resources to operate a clandestine enrichment facility using illicitly acquired low-enriched uranium, rather than attempting to acquire the fully enriched uranium directly.

The analyses which formed a basis for this conclusion point to one specific ancillary recommendation which is that the protection (classification) of enrich-

ment technology be continued. This is the case because while enrichment technologies are expected to remain highly sophisticated for the foreseeable future, any breakthrough which would dramatically change the ease by which uranium might be upgraded could jeopardize the otherwise insignificant risk associated with both natural uranium and low-enriched uranium. Classification of technologies and the safeguarding of critical equipment and materials would provide added assurance that the risks from source and low-enriched uranium do not become significant.

APPENDIX

A. OVERVIEW

Uranium isotopes separation technology has been under intensive development throughout the world since shortly after World War II. As a result of these efforts, today there are three main technical alternatives for the enrichment of uranium: gaseous diffusion, gas centrifuge, and the Becker nozzle or jet nozzle (11). However, intensive development is currently underway on other processes, including the laser and Fenn Shock methods.

All of the known potential heavy-isotope separation techniques, with the exception of laser enrichment process, achieve only an extremely small enrichment with a single application of the technique. Therefore, repeated application of the technique is required to separate feed materials at a particular concentration into fractions at substantially different concentrations. As a result of these limits, isotopic enrichment is most efficiently accomplished with a series of the separation devices called a "cascade." The effort involved in accomplishing this isotope separation is referred to as separative work and is measured in Separative Work Units (SWU).

Gaseous diffusion plants are presently the prime producers of enriched uranium and can be characterized as very expensive, large scale facilities with a correspondingly large capital investment and power consumption. For example, the gaseous diffusion plants operated by the United States currently represent the free world's largest enrichment facilities. The U.S. Energy Research and Development Agency (ERDA) has three such large enrichment facilities, located at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. All of the present, domestic, nonexperimental enrichment plants use the gaseous diffusion method. Future domestic facilities may use other methods currently under development, which may permit the operation of smaller facilities.

Alternate enrichment processes currently under development in the United States include the gas centrifuge and laser processes. Gas centrifuge technology, which was tested early in the Manhattan Project, and later revived in the late 1950's and early 1960's, is presently being tested in pilot production facilities. Although their power consumption is approximately one tenth that of a gaseous diffusion plant, gas centrifuges have an inherently low throughput capability which requires a large number of cascades of the technically sophisticated machines operating in parallel.

It is significant to note that substantial research is being conducted in other countries on alternative enrichment approaches. Principal examples of these technologies are the Becker or "nozzle" process, developed by the West Germans, and an undisclosed process developed by the South Africans. Commercial facilities based on these processes are currently under development. In additon, there has been substantial Japanese (12, 13) and some limited domestic research into the possiblitiies of a "redox" (reduction/oxidation) ion-exchange process. A European consortium, Urenco-Centec, is also investigating the centrifuge process for commercial fuel production. (14) Other techniques such as electro-magnetic separation and thermal diffusion have been successful in separating heavy isotopes on a very small scale and are currently far from competitive on a commercial scale. Newer technologies, such as laser enrichment, are in the laboratory research stage of development and are not likely to be available for at least 5 to 10 years. (3,8,9,15)

It is important to note that a key aspect of these foreign national level approaches to enrichment capability is the attempt to utilize some intrinsic natural resources in lieu of advanced technology. Thus, processes which seem impractical based on the standards of a highly industrialized nation may be attractive to under-developed nations. A case in point is the approach embraced by the Brazilian Energy Plan. (14) It is based on the Becker process, which is feasible only because of the availability of large sources of hydro electrical power in Brazil. However, it is important to note that even such purportedly "low-technology" processes for separating uranium isotopes are based on significant capital and natural resources, well beyond the scope of any credible subnational clandestine activity.

B. PROCESS DESCRIPTIONS

B.1 Gaseous Diffusion

Isotopic separation by gaseous diffusion takes place because the lighter molecules in a gaseous mixture tend to move faster than the heavier molecules and consequently strike the walls of a diffusion chamber more frequently. If the diffusion-chamber walls have holes just large enough to allow passage of the individual molecules, without permitting bulk flow of the gas, more of the lighter molecules flow through the wall than the heavier molecules. Each stage in a diffusion plant requires a compressor to keep the feed material of the

stage at a higher pressure than the other (enriched) side of the barrier. This permits a net flow in a single direction through the barrier. Extremely large amounts of power are required to operate the compressors associated with this process. The known free world diffusion plants are listed below.

DIFFUSION PLANT CAPACITIES (16)

Plant Location	Country	Capacity (10^6kg SWU/year)
Oak Ridge, Tennessee	US	4.7
Portsmouth, Ohio	US	5.2
Paducah, Kentucky	US	7.3
Capenhurst	UK	0.4
Pierrelatte	France	0.4-0.5 (estimated)

Besides these plants, the USSR and China are known to have diffusion plants.

Construction of gaseous diffusion enrichment plants is a very large industrial and financial undertaking. Current U.S. estimate for a 8,750 tonne SWU/yr gaseous diffusion plant is about $3 billion. (17) The international plant being built by Eurodif (France 42.8%, Italy 25%, Spain 11.1%, Belgium 11.1%, and Iran 10%) in France is expected to cost 15,000 M francs, not including the four 900 MW(e) PWR nuclear plants that will be utilized to provide the necessary 2400 MW(e) for the diffusion plant. (18)

A common guage of the relative technical feasibility of the gaseous diffusion process as well as other uranium isotope separation processes has been defined as the maximum single-stage separations factor (Alpha*). It represents the maximum theoretical separation that can be achieved in a single step of the enrichment process. For the gaseous diffusion process it is related to the square root of the molar ratio of the masses involved. The relationship is derived as follows: (10)

$$\text{Kinetic Energy} = 1/2\, mv^2 \qquad (1)$$

$$1/2\, m_1 v_1^2 = 1/2\, m_2 v_2^2 \qquad (2)$$

$$\frac{v_1}{v_2} = \frac{\sqrt{m_2}}{\sqrt{m_1}} = \alpha^* \qquad (3)$$

Where (m) is the molecular mass, (v) is the molecular velocity, and subscripts (1) and (2) represent the two components to be separated. For the gaseous diffusion process using uranium hexafluoride, the theoretical separations factor is calculated as follows:

$$\frac{\sqrt{m_{U\,238\,F_6}}}{\sqrt{m_{U\,235\,F_6}}} = \frac{\sqrt{352}}{\sqrt{349}} = 1.0043 = \alpha^* \qquad (4)$$

However, in practice, achievable separations factors for the gaseous diffusion process are significantly less due to imperfection in materials, equipment design, and operation.

In these terms, the incremental change in enrichment per stage (Delta X) in the gaseous diffusion or other common enrichment processes is related to both uranium feed material enrichment (x_f) and actual separations factor (Alpha), as follows:

$$\Delta x = x_f \quad (\alpha - 1) \qquad (5)$$

For example, if a process has a separations factor of 1.0043, it would take approximately 62 stages to change the enrichment of natural uranium by 0.1% U-235. A similar effect (Delta X 0.1% U-235) could be produced in 5% U-235 feed material in approximately 10 stages. Thus, in any conventional separations process the enrichment per stage is defined as follows: (19)

$$x_p = \alpha\, x_f \qquad (6)$$

where x_p is the U-235 concentration of the product stream from the stage, x_f is the U-235 concentration of the feed stream to the stage, and Alpha is the actual separation factor for the enrichment process.

Another useful parameter is the estimate of the minimum number of stages (n) required for a particular degree of separation in a cascade. It can be calculated as follows. (20)

$$n = \ln \frac{X_p (1 - X_w)}{(1 - X_p) X_w} \quad \ln \alpha \qquad (7)$$

where X_w is the U-235 concentration of the waste stream from the cascade^w, X_p is the U-235 concentration of the product stream from the cascade, and Alpha is the actual separation factor of each stage in the cascade.

The separative work per unit of product ($(SW)_{e_p, f}$) in a gaseous diffusion cascade is defined in terms of the feed material enrichment (X_f) and product material enrichment (X_p), as follows: (20)

$$(SW)_{e_p, f} = (2X_p - 1) \ln \frac{X_p(1 - X_f)}{X_f(1 - X_f)} + \frac{(X_p - X_f)(1 - 2X_f)}{X_f(1 - X_f)} \qquad (8)$$

However, for the case being considered (low-enriched uranium; X_f 20% U-235), X_f is small with respect to both X_p (highly-enriched uranium) and unity (100% enrichment). This is the case because a clandestine group would probably not be interested in enriching feed material to a sufficiently high enrichment where it could be used for an efficient nuclear weapon (e.g., high reliability and yield). These enrichment and reliability advantages would most assuredly be sacrificed in favor of timeliness and capacity. As a result, it is assumed that clandestine isotopes-separation activities of any sort would be discontinued at the point where a crude nuclear explosive device, with a credible but not high reliability, could be built.

As a result of these assumptions (X_p and X_f much less than 1). Equation (8) can be simplified to the following approximation:

$$(SW)_{e_p, f} = \frac{X_p}{X_f} - 1 \qquad (9)$$

However, under the conditions where the U-235 concentration of the product is significantly higher than that of the feed stream (e.g., 1 much greater than X_p much greater than X_f), Equation (8) can be simplified even further, as follows:

$$SW_{e_p,f} \approx \frac{X_p}{X_f} \qquad (10)$$

As a result, feed material with a U-235 concentration of X_p would be approximately a factor of X_p/X_f times more useful as a feed for an enrichment facility than feed material with a U-235 concentration of X_f. Specifically, feed material of X_f enrichment is (X_f/0.7) more useful, as a feed for enrichment per unit of available separative work, than natural uranium. This relationship applies to all diffusion related enrichment processes.

Under conditions where the adversary has a sufficient supply of feed material to operate the enrichment process with a waste concentration (X_W) which is only slightly less than X_f, then Equation (7) becomes

$$n \approx X_p/X_f \qquad (11)$$

Based on these relationships, the separative work required to enrich a unit product of uranium is related to the ratio of the product and feed stream enrichment. The following table shows examples of the amount of separative work per unit of product that is required to raise the enrichment of 0.7, 5.0, 10.0, and 20.0% U-235 feed materials:

Product U-235 Concentration (X_p)

Feed U-235 Concentration(X_F)	5.0	10.0	20.0	90.0
0.7	6.1	13.3	27.6	127.6
5.0	—	1.0	3.0	17.0
10.0	—	—	1.0	8.0
20.0	—	—	—	3.5

For example, 6.1 separative work units are required to raise the enrichment of natural uranium from 0.7% to 5% U-235. Conversely, 5.0% U-235 material is 7.5 times (127.6/17.0) better than 0.7% U-235 material as a feed for further enrichment. Further, 10% is 2.2 times or (13.3/6.1) better than 5%, and 20% is 2.1 times (27.6/13.3) better than 10%. The degree of advantage is nearly linearly related to enrichment.

A combination of Equations (9) and (11) gives the relationship between the number of stages in the cascade and the separative work of which it must be capable:

$$n = \frac{\ln [(SW)e_p,f + 1]}{\ln \alpha} \qquad (12)$$

Since $\ln \alpha$ is about 10^{-3},

$$n \approx 10^3 \ln [(SW)e_p,f + 1] \qquad (13)$$

Thus, even when the separative work required is near unity, several hundred separation stages are still required to satisfactorily establish a credible enrichment capability.

B.2 **Centrifuge**

The gas centrifuge process is based on a rotating cylinder which imparts a centrifugal force to compress UF_6 molecules to the outer radius of the cylinder. However, the thermal velocities of the molecules tend to keep the gas molecules evenly distributed throughout the available volume. Since the latter effect is larger for lighter molecules, there are relatively fewer lighter molecules at the outer radius of the centrifuge.

The centrifuge process can achieve a relatively large separation factor, but invariably has a smaller throughput rate than a diffusion stage. For a centrifuge, operating isothermally, the maximum separative capacity is calculated as follows: (9)

$$\text{Max SW} = \pi\rho D(Z/2)\ [(m_2 - m_1)\ \mu^2/2RT]^2 \qquad (14)$$

where SW = separative work

π = constant

ρ = gas density

D = diffusivity

m_2-m_1 = isotopic mass difference

Z = bowl length

μ = peripheral velocity

T = absolute temperature

R = gas constant

It is important to note that the separative work for the centrifuge is proportional to the difference in molecular weights and not to the ratio of molecular weights as was the case for the gaseous diffusion process. This relationship (Equation 14) also indicates the importance of a rapidly spinning cylinder (4th power of the peripheral volocity) and a low temperature.

In 1960 results were published (21) on centrifuges approximately one foot long, spinning at 350 meters/second and at a temperature of 33°C. These parameters yielded separation factors of 1.1-1.2 (compared to the maximum of 1.004 for gaseous diffusion). This advancement indicated that relatively few centrifuges needed to be connected in series (vertical) to achieve substantial changes in concentration. However, because of extremely low flow rates, large numbers of the shorter cascades operated in parallel (horizontal) are required for a practical level of throughput.

The primary technology difficulties associated with gaseous centrifuges are in the design and production of light weight centrifuge machines that have a low friction coefficient and low power consumption. The light weight centrifuge bowls must be able to withstand the centrifugal forces derived from the high peripheral speeds. Several countries have produced successful machines with component reliability of 98% to 99%. However, these materials, processes and equipment are rigidly protected.

The free world involvement in centrifuge technology is primarily in the U.S., the trilateral agreement countries of Urenco/Centec (UK, West Germany, and the Netherlands) and in the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. Typical national development expenditures in

TABLE A1

Feed Enrichment (%)	Waste Enrichment (%)	Product Enrichment (%)	Feed Weight (kgU)	Separative Work Units (SWU)	Number of Gas Centrifuge Units Per Year
0.72	0.2	90	6753	8827	1765
		93	6754	8849	1770
		97	6755	8891	1778
	0.3	90	8344	7485	1497
		93	8344	7506	1500
		97	8344	7551	1510
	0.4	90	10928	6607	1321
		93	10928	6632	1326
		97	10928	6672	1334
3	0.7	93	1548	2404	481
	0.9	93	1688	2188	438
	1.1	93	1858	2022	404

these countries for the last few years have been on the order of $20 million/year. (3)

The Urenco/Centec centrifuge effort has two 25,000 SWU/yr. pilot facilities in operation, and it is expected that a German operation with a similar capacity will come on line soon. In addition, there are several consortiums of European countries that are producing ultra centrifuge machines or components of ultracentrifuge machines: (22)

Germany—MAN, Dornier, Erno, and Interatom, Uronet

Netherlands—DSM, Shell Kernenergies, VMF, Ryn-Schelde and RCN

UK—BNFL

The Japanese effort (PNC) is presently much smaller with an 18-cascade (10 machines per cascade) plant operating since late 1974 and a 250-machine formation expected. (12) A PNO 10,000-machine pilot plant is expected to be operational in 1978. (13)

The amount of separative work involved for various feed and waste enrichments and the estimated number of centrifuges necessary to produce 35 kg of U-235 per year are given in the following table (A SWU capacity of 5 kg per machine per year has been assumed in these calculations): (3) (See Table A1 above)

Based on these data, it is apparent that a 2000 unit centrifuge plant could support a 35 kg/yr highly enriched uranium requirement. If the feed were slightly enriched uranium, such as that used in the LWR's, the number of centrifuges required is reduced by roughly two thirds.

B.3 **Becker Nozzle**

The Becker nozzle process (3), which is being developed in Karlsruhe, West Germany (and possibly in South Africa), has progressed to the stage where pilot production plants can be built. Several variations of the nozzle process exist, but the one closest to commercial application is based on a process where uranium hexafluoride gas (mixed with hydrogen) is pumped through a long slit, forming a rapidly moving sheet of gas. The gas strikes a curved wall, bending the gas sheet through 180 degrees. Centrifugal forces then carry the heavier uranium-238 (which makes up approximately 99.3 percent of the gas) to the outer surface of the sheet, where a knife-like barrier pares it off. The lighter fraction, now slightly enriched in uranium-235, is routed through hundreds of additional stages to reach the desired level of enrichment.

Advantages of the nozzle process are that it does not require the hard-to-make porous barriers of a gaseous diffusion plant and that it avoids the highly stressed moving parts of an ultracentrifuge. One disadvantage of the nozzle process is that it consumes more electric power than a gaseous diffusion plant and at least 10 times the power of an equivalent centrifuge plant. This disadvantage is not significant, however, where electric power is not expensive on a national basis as in Brazil or Switzerland.

In South Africa a pilot enrichment plant which is thought to be based on the nozzle technique is operating. Plans have been developed to construct a 5,000 tonne SWU/yr production plant for operation in 1984. (3)

B.4 **Laser**

Laboratory demonstration of laser enrichment for light elements (e.g., SF_6) has been announced by the US and USSR. This process theoretically would require only a single stage (practically it will require several), and power consumption requirements are thought to be on the same order of magnitude as that for the ultracentrifuge process. A finely tuned, high power, CO_2 laser differentially excites the molecules containing the isotope of interest allowing a chemical or physical separation of the excited species from the unexcited species. The removal process for the excited molecules has recently been described. (15)

The laser process could potentially be a very effective method for inexpensively producing enriched uranium. However, as of yet, even though under intensive development, it has only been demonstrated on very small quantities of heavy elements. The amount of development effort that will be required and the time schedule needed to bring this method to the point of larger scale feasibility might be expected to take at least 5 to 10 years.

TABLE A2

SUMMARY COMPARISON OF PROCESSES[9]

Process	Separation Factor, a - 1	Specific Energy Consumption kw/kg USW/yr		Uranium Inventory kg/kg USW/yr
		Theoretical Minimum	Practical	
Gaseous Diffusion	0.0043	0.073	0.266	0.1
Distillation of UF_6	0.00009	— —	0.62	150
Liquid-Liquid Chemical Exchange, $NOUF_6$-UF_6	0.0016	— —	— —	— —
Redox Ion Exchange	0.0005	— —	0.71	22
Mass Diffusion with UF_6 and N43	0.00281	0.17	1.0-1.2	— —
Thermal Diffusion with UF_6	— —	61	— —	— —
Electromigration in UCl_4	— —	— —	1817	— —
Molecular Distillation	0.0043	0.073	— —	— —
Isotope Chopper	0.0043	0.073	— —	— —
Becker Separation Nozzle	0.015	— —	0.656	— —

B.5 **Other Techniques**

An earlier study (9) has analyzed the technical and economic capabilities of twenty-two other alternatives to current uranium separations technology. In this case, the gaseous diffusion process was used as a basis for comparison. Secondary alternative processes are summarized below.

PHASE EQUILIBRIUM SEPARATION PROCESSES

1. Fractional Distillation
2. Gas-Liquid Absorption
3. Fractional Sublimation
4. Liquid-Liquid Extraction
5. Fractional Crystallization

CHEMICAL EXCHANGE SEPARATION PROCESSES

6. Exchange Distillation
7. Gas-Liquid Chemical Exchange
8. Liquid-Liquid Chemial Exchange
9. Exchange Chromatography
10. Redox Ion Exchange

DIFFUSION SEPARATION PROCESSES

11. Sweep and Mass Diffusion
12. Carrier Diffusion
13. Thermal Diffusion
14. Standing Sound Waves
15. Liquid Diffusion
16. Electrical Fields in Liquids

MOLECULAR FLOW PROCESSES

17. Molecular Distillation
18. Isotope Chopper

AERODYNAMIC PROCESSES

19. The Vortex Tube
20. The Fenn Shock Process
21. **ELECTROMAGNETIC METHODS**
22. **NUCLEAR SPIN PROCESSES**

A major conclusion of the study was that many of the processes have such major qualitative disadvantages, relative to alternative methods (e.g., gaseous diffusion), that quantitative evaluation of their use is not warranted. However, for a limited number of the processes with some promise, quantitative assessment has been made of appropriate process characteristics to facilitate comparison with the gaseous diffusion process. This comparison is summarized in Table A2.

For most of the processes listed, it has been possible either to estimate a separation factor or to set an upper bound for it. The number of stages or transfer units needed for a given degree of separation is inversely proportional to the separation factor tabulated, alpha -1. Of all the processes considered, only the Becker separation nozzle and gas centrifuge processes have higher separation factors than gaseous diffusion. Liquid-liquid chemical exchange between $NOUF_6$ and UF_6 has the highest separation factor of all the potentially reversible processes. However, the magnitude of the separation factor is at best only suggestive of the relative merit of a process. Indices also related to this study are the specific energy consumption and the specific uranium inventory given in the last three columns of Table 1.

The specific energy consumption is expressed as kilowatts of useful work per kilogram uranium separative work (SWU) per year of plant capacity. The standard of comparison is the value of 0.266 kw/kg SWU/yr predicted for a new gaseous diffusion plant. None of the processes for which it was possible to evaluate the specific energy consumption for a practical plant comes within a factor of two of matching the gaseous diffusion process.

For some of the processes, thermodynamic theory permits evaluation of a minimum theoretical specific energy consumption; this is a convenient index for comparing processes when a value for a practical plant isn't available. With this theoretical index, also, gaseous diffusion has the lowest specific energy consumption. It is possible, however, that the specific energy consumption of one of the potentially reversible processes might be lower than gaseous diffusion if a system could be found with a separation factor of the order of 1.001 and a reflux system with low energy requirements.

The specific uranium inventory, expressed as kilograms of uranium plant inventory per unit plant

capacity in kilograms uranium separative work per year is another important index. The equilibrium time of a plant performing a given degree of enrichment is proportional to this index, as is the contribution of the cost of uranium inventory to the cost of separative work. For example, the specific inventory for distillation of UF_6 of 150 kg U/kg SWU/yr represents an equilibrium time of 28 years in a plant enriching natural uranium to 3.2%. The exact specific inventory of the gaseous diffusion process is a classified number, but it is probably less than 0.1 kg U/kg SWU/yr. Neither distillation of UF_6 nor redox ion exchange comes within a factor of 100 of this value, and it is doubtful whether any of the other processes except the Becker or gas-centrifuge processes could come close to it.

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THE EFFORT OF OBTAINING A RANDOM SAMPLE*

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It is frequently necessary in controlling SNM materials to take a random sample from a relatively large population of items (e.g., fuel elements) which are identical except that each has a unique serial number. If a record of the storage location of each item by serial number and container number is kept, then a random sample can be taken by obtaining a random list of serial numbers together with their recorded locations. It is assumed that the storage within any container is random. The following is a description of the effort required to locate all the listed items.

If a defect is defined as an element missing from its recorded storage location, and no such defects are found, then a statistical statement can be made about the veracity of the records and the limit to the number of items missing from the inventory. If one or more elements are not in their expected locations, the population is defective and some more extensive action must be taken. In order to compute a sample size, a limit is first defined such that, if that number of defects exists in the population, the sample examined will contain one or more of them some large fraction of the time. The latter value, called the confidence level CL, is usually taken as 95%, and a frequent value taken for the fractional number of defects, f, is 1% of the total. The sample size, or the number of items to be examined, is then computed from the equation

$$n = (N - (D - 1)/2)(1 - \beta^{1/D}) \qquad (1)$$

where n is the sample size
N is the total number of items in the population
D is the number of defective items = fN
$\beta = (1 - CL)$

This is an approximation derived from the hypergeometric equation for zero defects in the sample.[1]

The sample sizes computed from this equation depend on N, the total number of items in the population. For example, taking f = .01 and β = .05: if N = 100, the sample size is n = 95; for N = 1000, n = 258. The sample size increases slowly with increasing N and reaches a limit of 298 for values of N above about 77,240.

Suppose that a container has M total items stored in a random manner. Suppose also that the list of n random serial numbers indicates that m of them are in this particular container. The number of items which would have to be examined, serial numbers read, will vary from m, if the first m items happen to be the ones sought, to M, if the last item in the container is the last of the m items sought. The average number of items, k, that will have to be examined in order to find the m specific items that are supposed to be in a particular container is

$$k = m(M + 1)/(m + 1) \qquad (2)$$

A derivation of this formula is given at the end of this paper.

If a container has 100 items and one is looking for 1 particular item, one would have to examine, on the average, 50.5 items. If m is larger, the average number of items that would have to be examined in order to find all m particular items is also larger. These average numbers, k, are listed in the second column of Table I, below, for the case when M = 100.

Example: Suppose that we have 10,000 fuel elements in serialized storage, 100 elements in each of 100 containers. 1) What sample size is necessary to be 95% confident that less than 1% of them are defective? 2) On the average, how many items will have to be examined (serial numbers read) in order to locate all items of the sample?

* Work performed under the auspices of the U.S. Energy Research and Development Administration and the Nuclear Regulatory Commission.

1) From Eq. 1, using the above values for N, CL, and f, we compute n = 294.

2) The expected percentages of containers which have 0, 1, 2, etc., of the sample items are the same as the percentages of samples of 100 items containing 0, 1, 2, etc., particular items which are drawn from an infinite population having the fraction of particular items equal to n/N = .0294. These values are computed from the binomial distribution equation and listed in column 3 of the table. Column 4 lists the number of containers, C, that we would expect to find with 0, 1, 2, etc., sample items. This is simply a rounding of column 3, in this case, because there are 100 containers, and column 3 must add to 100. In other cases, the numbers in column 4 would be these percentages (column 3) of the total number of containers. Column 5 is obtained by multiplying corresponding elements of columns 1 and 4 to obtain the total number of sample items in containers containing 1, 2, 3, etc., of them. Column 6 is obtained by multiplying corresponding elements of columns 2 and 4. The total under column 6 is the total number of items that would, on the average, have to be examined (i.e., serial numbers read) in order to locate the 294 items of the sample. This number is 6878.

TABLE I.

m	k	%	C	m·C	k·C
0	---	5.0	5	--	
1	50.50	15.3	15	15	758
2	67.33	23.0	23	46	1549
3	75.75	22.7	23	69	1742
4	80.80	16.7	17	68	1374
5	84.17	9.7	10	50	842
6	86.57	4.6	4	24	346
7	88.37	2.0	2	14	177
8	89.77	0.7	1	8	90
9	90.90	0.2	--	--	
		Total	100	294	6878

As the number of containers increases and the number of items per container decreases, then the number of items which would have to be examined decreases for the same population size. In the limit, when there is one item per container, the number of items which would have to be examined would be reduced to the sample size (i.e., 294 in the above example). This could be accomplished by identifying each location within the existing containers and recording this as part of the address for each item.

Table II shows the number of items that would, on the average, have to be examined in obtaining a sample of size 258 and 294 from populations of 1000 and 10,000, respectively, when the items are stored 10, 25, 50, or 100 per container. An examination shows that the smaller the number of items per container, the smaller the number of items handled to obtain the same sample. The fraction of the total population which it is necessary to examine decreases with increasing population size for the same method of storing.

TABLE II.

M \ N, n	1000 258	10,000 294
10	727	1482
25	885	3067
50	944	4882
100	970	6878

Derivation of Equation 2

Consider a container holding M items which are identical except that each has a unique serial number. How many of the M items, on the average, will have to be examined in order to locate m particular ones? The number of ways that the nth item examined will be the mth item sought is equal to the number of ways that the other m - 1 items could be found in n - 1 examinations. This is

$$P_n = (n - 1)!/(m - 1)!(n - m)! \quad (3)$$

The average number of items that would have to be examined is the average of all possible values of n, each weighted by the number of ways that they could occur.

$$k = \frac{\sum_{n=m}^{M} nP_n}{\sum_{n=m}^{M} P_n} \quad (4)$$

Substituting Eq. 3 for P_n and cancelling the constant term (m - 1)! which occurs in each term of both the numerator and denominator, we have

$$k = \frac{\sum_{n=m}^{M} n(n - 1)!/(n - m)!}{\sum_{n=m}^{M} (n - 1)!/(n - m)!} \quad (5)$$

Expand this, noting that $n(n-1)! = n!$. Factor $m!$ from the numerator and $(m-1)!$ from the denominator and note that $m!/(m-1)! = m$. We have

$$k = m \frac{1 + (m+1) + \frac{(m+2)(m+1)}{2!} + \cdots + \frac{M!}{(M-m)!m!}}{1 + m + \frac{(m+1)m}{2!} + \cdots + \frac{(M-1)!}{(M-m)!(m-1)!}} \quad (6)$$

The sum of the first i terms in the denominator is equal to the ith term of the numerator. As each term in both the denominator and numerator is related to the previous term in a systematic way, we can see that the sum of all terms in the denominator is equal to the last term in the numerator. A comparison of corresponding terms in the numerator and denominator shows that they are the same, except that each factor in the numerator term is increased by 1. The sum of the numerator terms is then equal to its last term with these factors increased by 1. We then have

$$k = m \frac{(M+1)!}{(M-m)!(m+1)!} \Big/ \frac{M!}{(M-m)!m!}$$

$$= m(M+1)/(m+1) \quad (7)$$

Summary and Conclusions

This method of sampling a population of items is very inefficient and weak. A large fraction of the population would have to be examined in order to obtain the sample, and the resulting statistical statement would be quite limited. If the purpose of the exercise is to demonstrate that no items are missing, a 100% piece count could be made with little more, and perhaps less, effort, and the resulting statement would be quite positive. If the purpose is to obtain a sample to be measured, it would be far more efficient to prorate the sample size over all containers according to their content, and then select that number of items from each container in some random manner. Alternatively, if each position within a container is identifiable, then a random list of containers and positions could be made, and the items occupying these positions could be taken as the sample. If the only reason for maintaining a record of item locations by serial number is for accountability purposes, the effort so expended is superfluous.

[1]Reference:

Jaech, John L., "Statistical Methods in Nuclear Material Control," p. 327, TID26299, U. S. Government Printing Office, Washington, DC, 20402.

Annual Meeting Preview

(Continued from page 10)

Considering the global scale of the proliferation problem, it seems clear that if there is to be any hope of meeting realistic non-proliferation objectives, nuclear supplier nations must meet the legitimate fuel cycle needs of other nations, some of whom have little alternative but to rely largely on nuclear power for their energy needs. By assuring such nations that their legitimate fuel cycle needs will be met by modern, efficient, large plants (e.g., multinational facilities, internationally safeguarded, and strategically located in key regions of the world) they may be much less inclined to build economically unattractive, small scale reprocessing or enrichment plants of their own. Such supply-oriented, positive nuclear policies have a far greater chance of succeeding than negative, denial-oriented policies which, history tells us, are almost certainly doomed to failure.

These and other important domestic and international issues involved in "Safeguarding the Nuclear Fuel Cycle," will be addressed at the Institute's 1977 Annual Meeting by authorities and experts from industry, government and the international nuclear community. Our technical program committee, chaired by **Gary Molen** of Allied-General Nuclear Services, has assembled an outstanding group of speakers and panelists (including a special surprise luncheon speaker Thursday, June 30). Local arrangements chairman, **Joe Sapir** and his committee are carefully working out the many details required for a smooth running meeting with this year's anticipated record number of attendees. (E.g., this year we've even come up with a new registration procedure designed to smooth out the usual opening morning rush on the registration desk!) Our ladies' program this year is in the very capable hands of **Barbara Hammond** and **Alvida Jones,** both resident experts on the many points of interest and attractions in the Washington area. So all in all it looks like we've once again got a real winner coming up, this time in the nation's capital—where the action is! Hope to see you there in June.

COMBINING ESTIMATES OF MEASUREMENT PRECISIONS FROM DIFFERENT EXPERIMENTS

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Introduction

Commonly, estimates of measurement precisions are derived from several sources. These may include data routinely generated by an ongoing measurement control program, data from experiments conducted to investigate specifically the effects of certain variables on total errors of measurement, shipper-receiver differences data, data from participation in inter-laboratory experiments, data derived from inspections by audit groups, etc. In the calculation of limits of error for material unaccounted for and other accountability quantities, given values of the measurement precisions are used based on all available pertinent data sources. The problem of how to combine the information from all these data sources to arrive at overall estimates of the precisions of interest is considered in this paper.

The estimation approach is based on the weighted least squares principle. Complications arise because in many instances the appropriate weights are functions of the unknown parameters to be estimated. This suggests the need for an iterative approach, which is usually too cumbersome to attempt by hand. A computer program, WEVCO, has been developed to facilitate obtaining the weighted least squares estimates of the parameters. The program listing is included as part of this paper.

The Model

The data consist of n estimates of linear combinations of k parameters with $k \leq n$. Let these n estimates be designated by $x_1, x_2, \ldots, x_n$ and let the k parameters be $u_1, u_2, \ldots, u_k$. The equation i is of the form:

$$c_{i1}u_1 + c_{i2}u_2 + \ldots + c_{ik}u_k = x_i \qquad (1)$$

so that in matrix notation the n equations may be written

$$Cu = x \qquad (2)$$

where C is the n by k matrix of coefficients, u is the k by 1 column matrix of parameters, and x is the n by 1 column matrix of estimates.

The problem is to obtain estimates of the u's. A weighted least squares approach is used. With this estimating procedure, the quantity Q is minimized with respect to the u's

$$Q = \sum_{i=1}^{n} a_i(x_i - c_{i1}u_1 - c_{i2}u_2 - \ldots - c_{ik}u_k)^2 \qquad (3)$$

where a_i is the "weight" for equation i, given by

$$a_i = (\text{variance } x_i)^{-1} \qquad (4)$$

In (4), variance x_i is the sampling variance of x_i and is a function of the unknown parameters. Conceptually, each a_i could be written as a function of the u's in (3), Q could then be differentiated with respect to each of the u's, equated to zero, and the resulting k equations solved simultaneously for the u's. However, the resulting equations are very difficult to solve and an iterative approach is suggested. With the iterative approach, initial values are assigned the u's, the a's can then be assigned values based on these input u's, and then Q is differentiated with respect to the u's, with the results equated to zero and the k equations solved simultaneously for the u's to obtain a set to be used in the next iteration. This procedure continues until convergence to specified criteria is attained.

A few words on finding variance x_i are in order. Often, x_i will be a simple variance calculated for data drawn from a normal population with variance σ^2. In this event, it is well known that variance x_i is $2\sigma^4$ divided by the degrees of freedom. The σ^2 in question, of course, is a linear combination of the unknown u's. As another common possibility, a given x_i may be derived from a Grubbs' analysis of paired data in which the form of variance x_i is given by Grubbs [1].

Once the expressions for variance x_i are written for all i, the weighted least squares estimates of the u's to use in the next iteration are found. Upon differentiating Q with respect to u_j and equating to zero, we get

$$\frac{\partial Q}{\partial u_j} = 2 \sum_{i=1}^{n} a_i \left(x_i - \sum_{\ell=1}^{k} c_{i\ell}u_\ell\right)(-c_{ij}) = 0$$

from which

$$\sum_{i=1}^{n} a_i c_{ij} \sum_{\ell=1}^{k} c_{i\ell}u_\ell = \sum_{i=1}^{n} a_i c_{ij} x_i; \; j=1,2,\ldots,k \qquad (5)$$

To simplify the notation, let

$$w_{j\ell} = \sum_{i=1}^{n} a_i c_{ij} c_{i\ell} \qquad (6)$$

and let $v_j = \sum_{i=1}^{n} a_i c_{ij} x_i \qquad (7)$

Then, the system of k equations to be solved are, in matrix notation,

$$Wu = v \qquad (8)$$

where W is a symmetric k by k matrix, u is the k by 1 matrix of parameters, and v is the k by 1 matrix with element j given by (7). The solution of (8) is, in matrix notation,

$$u = W^{-1} v \qquad (9).$$

WEVCO Computer Program

A computer program is helpful in this estimation procedure unless k=2 in which case calculations are easily performed on a desk calculator. The Fortran programs consist of the main program, WEVCO, a matrix inversion subroutine, MAINV, and a user supplied subroutine, WEVMOD. In the subroutine WEVMOD, the user includes the a's as functions of the u's, the elements of W given by (6), writing these as functions of the unknown a's, and also the elements of v given by (7), again as functions of the a's. The program WEVCO reads the input data including the initial values assigned the u's to form the u matrix. It then calls subroutine WEVMOD to calculate matrices W and v, and calls subroutine MAINV to invert the matrix W. The matrix inversion program uses a modified Doolittle technique where an identity matrix is attached alongside. The original matrix and the computations performed on both matrices reduce the original matrix to the identity and the identity to the resultant inverse. WEVCO then performs the matrix multiplication in (9) to obtain the u values for the next iteration. After each iteration the matrices W, v and u are printed and the new elements of u are compared in absolute value with the elements of u after the previous iteration. If the absolute differences of all elements are less than the convergence criterion, the iterative process is concluded and matrix u contains the final estimates. If convergence is not reached after a given maximum number of iterations, the iterative process is concluded with an appropriate message printed.

Example

The example given in Section 4.0 of [2] is used to illustrate the weighted least squares approach. With reference to that notation, make the identification:

$$u_1 = \sigma_s^2 \qquad u_2 = \sigma_t^2 \qquad u_3 = \sigma_a^2$$

The C and x matrices are as follows: with n=12 estimates and k=3 parameters.

$$C = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 0.5 \\ 0 & 1 & 1 \\ 2 & 2 & 0 \\ 2 & 1 & 0.5 \\ 2 & 1 & 1 \\ 2 & 0 & 1.5 \\ 2 & 1 & 0.5 \end{bmatrix} \qquad x = \begin{bmatrix} 15.8705 \\ 7.0960 \\ 2.8561 \\ 0.6724 \\ 7.3294 \\ 9.7890 \\ 4.0947 \\ 19.3351 \\ 21.2291 \\ 12.6507 \\ 13.3942 \\ 12.2458 \end{bmatrix}$$

In (2), a_i is given for i=1, 3, and 7. These are rewritten below along with a_i for the remaining x values.

$$a_1 = 8.5\ (u_1+u_2)^{-2}$$

$$a_2 = 20\ u_3^{-2}$$

$$a_3 = [0.1538\ u_2^2 + 0.5483\ (u_2+u_3) + 0.0769\ u_2u_3]^{-1}$$

$$a_4 = [0.1538\ u_3^2 + 0.5483\ (u_2+u_3) + 0.0769\ u_2u_3]^{-1}$$

$$a_5 = [0.0556\ (u_1+u_2)^2 + 0.0278\ (u_1+u_2)(u_1+0.5u_3)]^{-1}$$

$$a_6 = [0.0556(u_1+0.5u_3)^2 + 0.0278(u_1+u_2)(u_1+0.5u_3)]^{-1}$$

$$a_7 = 3.5\ (u_2+u_3)^{-2}$$

$$a_8 = 3.5\ (2u_1+2u_2)^{-2}$$

$$a_9 = 3.5\ (2u_1+u_2+0.5u_3)^{-2}$$

$$a_{10} = 3.5\ (2u_1+u_2+u_3)^{-2}$$

$$a_{11} = 3.5\ (2u_1+1.5u_3)^{-2}$$

$$a_{12} = 3.5\ (2u_1+u_2+0.5u_3)^{-2}$$

The W matrix is calculated from (6). Note that the matrix is symmetric.

$$w_{11} = a_1+a_5+a_6+4a_8+4a_9+4a_{10}+4a_{11}+4a_{12}$$

$$w_{12} = a_1+a_5+4a_8+2a_9+2a_{10}+2a_{12}$$

$$w_{13} = 0.5a_6+a_9+2a_{10}+3a_{11}+a_{12}$$

$$w_{22} = a_1+a_3+a_5+a_7+4a_8+a_9+a_{10}+a_{12}$$

$$w_{23} = a_7+0.5a_9+a_{10}+0.5a_{12}$$

$$w_{33} = a_2+a_4+0.25a_6+a_7+0.25a_9+a_{10}+2.25a_{11}+0.25a_{12}$$

The v matrix is calculated from (7).

$$v_1 = 15.8705\ a_1 + 7.3294\ a_5 + 9.7890\ a_6 + 38.6702\ a_8 + 42.4582\ a_9 + 25.3014\ a_{10} + 26.7884\ a_{11} + 24.4916\ a_{12}$$

with v_2 and v_3 calculated similarly.

As noted in the appendix, the a's, w's, and v's are inputted along with initial values, $u_1=u_2=u_3=1$. With a convergence criterion of 0.0001 for each parameter, chosen arbitrarily, the final estimates of the parameters are found after 9 iterations.

The estimates are:

$$\hat{u}_1 = \hat{\sigma}_s^2 = 6.697$$

$$\hat{u}_2 = \hat{\sigma}_t^2 = 2.804$$

$$\hat{u}_3 = \hat{\sigma}_a^2 = 5.718$$

Summary

A computer program, WEVCO, is listed in the appendix. This provides weighted least squares estimates of precisions where precisions are estimated individually and/or in various combinations from a number of separate experiments. The weights are functions of the unknown parameters to be estimated, and an iterative estimation procedure is used.

References

[1] Grubbs, F. E., "On Estimating Precision of Measuring Instruments and Product Variability", J. Amer. Stat. Assoc., 43, 1948.

[2] Jaech, J. L., "Case Studies on the Statistical Analysis of Safeguards Data", Safeguarding Nuclear Materials, Vol. 1 (Proceedings of Vienna Symposium), 1975.

APPENDIX

```
C      *****    WEVCO    *****
C
C      WEIGHTED ESTIMATES OF VARIANCE COMPONENTS.
C
C      INPUT
C      *****
C
C         CARD  COLS     VAR      DESCRIPTION
C         ----  ----     ---      -----------
C           1   1-80     ITITL    JOB TITLE
C           2   1-5      MIT      MAXIMUM ITERATIONS ALLOWED
C           3   1-15     CONV     CONVERGENCE CRITERION
C           4   1-5      N        NUMBER UNKNOWN PARAMETERS
C           5   1-80     IFMT     VARIABLE FORMAT FOR READING UL
C           6            UL       INITIAL U VECTOR
C
C         IR = CARD READER
C         IW = LINE PRINTER
      DATA  IR,IW/5,6/
C
      DIMENSION  UL(10), U(10), W(10,10), WI(10,10), V(10)
      DIMENSION  ITITL(80), IFMT(80)
C
      READ(IR,1000)  ITITL
      READ(IR,1010)  MIT
      READ(IR,1020)  CONV
      READ(IR,1010)  N
      READ(IR,1000)  IFMT
      READ(IR,IFMT)  (UL(I),I=1,N)
C
      WRITE(IW,1030)
      WRITE(IW,1040)  ITITL
      WRITE(IW,1050)  MIT, CONV, N
      WRITE(IW,1060)
      WRITE(IW,1070)  (UL(I),I=1,N)
C
      ITER = 1
C        CALL MODEL TO CALCULATE W AND V.
   10 CALL WEVMOD (N,UL,W,V)
C        INVERT MATRIX W.
      CALL MAINV (W,WI,N,NSOL)
      IF(NSOL.NE.0)  GO TO 90
C        MULTIPLY WI AND V.
   20 CONTINUE
      DO 30 I=1,N
      U(I) = 0.
      DO 30 J=1,N
      U(I) = U(I)+WI(I,J)*V(J)
   30 CONTINUE
C        PRINT RESULTS.
      WRITE(IW,1080)  ITER
      WRITE(IW,1090)
      DO 40 I=1,N
```

```
      WRITE(IW,1070)  (W(I,J),J=1,N)
   40 CONTINUE
      WRITE(IW,1100)
      WRITE(IW,1070)  (V(I),I=1,N)
      WRITE(IW,1110)
      WRITE(IW,1070)  (U(I),I=1,N)
C        CHECK FOR CONVERGENCE.
      DO 50 I=1,N
      T = ABS(UL(I)-U(I))
      IF(T.GT.CONV)  GO TO 60
   50 CONTINUE
      GO TO 100
C        CHECK FOR MAXIMUM ITERATIONS.
   60 IF(ITER.GE.MIT)  GO TO 80
      DO 70 I=1,N
   70 UL(I) = U(I)
      ITER = ITER+1
      GO TO 10
   80 WRITE(IW,1120)
      GO TO 100
   90 WRITE(IW,1130)  ITER
  100 STOP
 1000 FORMAT( 80A1 )
 1010 FORMAT( I5 )
 1020 FORMAT( F15.0 )
 1030 FORMAT( 1H1//20X,21H*****   WEVCO   *****///
     X        10X,41HWEIGHTED ESTIMATES OF VARIANCE COMPONENTS// )
 1040 FORMAT( 5X,80A1// )
 1050 FORMAT( 10X,I10,29H MAXIMUM NUMBER OF ITERATIONS/
     X        10X,F10.6,22H CONVERGENCE CRITERION/
     X        10X,I10,19H UNKNOWN PARAMETERS// )
 1060 FORMAT( 10X,16HINITIAL U VECTOR )
 1070 FORMAT( 2X,1P10E13.5 )
 1080 FORMAT( 1H0,4HITER,I3 )
 1090 FORMAT( 10X,1HW )
 1100 FORMAT( 10X,1HV )
 1110 FORMAT( 10X,1HU )
 1120 FORMAT( 1H0//10X,41HMAX ITERATIONS REACHED BEFORE CONVERGENCE )
 1130 FORMAT( 1H0//10X,40HINVERSE OF W DOES NOT EXIST IN ITERATION,I3 )
      END
C     *****   MAINV   *****
C
C        MATRIX INVERSION SUBROUTINE
C
C         A IS PLACED IN THE FRONT HALF OF B AND THE LAST HALF FIXED
C         AS THE IDENTITY.  THE FRONT HALF OF B IS THEN TRANSFORMED
C         TO THE IDENTITY.  THE LAST HALF BECOMING THE INVERSE OF A.
C         THE INVERSE IS THEN STORED IN AI.
C         NSOL IS A CONTROL SWITCH SET TO ZERO INITIALLY AND TO ONE
C         IF NO INVERSE EXISTS.
C
C
      SUBROUTINE MAINV (A, AI, N, NSOL)
C
      DIMENSION  A(10,10), AI(10,10), B(10,20)
C
      NSOL = 0
C
      IF(N.NE.1)  GO TO 10
```

APPENDIX - Continued

```
      AI(1,1) = 1./A(1,1)
      RETURN
   10 NM1 = N-1
      N1 = N+1
      N2 = 2*N
C
C          PLACE A INTO THE FIRST HALF OF B AND IDENTITY INTO LAST HALF
C     DO 30 I=1,N
      DO 20 J=1,N
      B(I,J) = A(I,J)
      JN = J+N
   20 B(I,JN) = 0.
      IN = I+N
   30 B(I,IN) = 1.
C
      K1 = 1
      I1 = 2
      J1 = 2
C
C          TRANSFORM FIRST HALF OF B TO IDENTITY
C
      DO 110 L=1,NM1
C
C          IF PIVOT IS ZERO, INTERCHANGE ROWS
C
      KP1 = K1+1
   40 IF(B(K1,K1).NE.0.)  GO TO 70
      IF(KP1.GT.N)  GO TO 60
      DO 50 JK=K1,N2
      T = B(K1,JK)
      B(K1,JK) = B(KP1,JK)
   50 B(KP1,JK) = T
      KP1 = KP1+1
      GO TO 40
C
   60 NSOL = 1
      RETURN
C
C          IF PIVOT NON-ZERO, DIVIDE AND INTRODUCE ZEROS BELOW DIAGONAL
C
   70 T = B(K1,K1)
      DO 80 J=K1,N2
   80 B(K1,J) = B(K1,J)/T
      DO 100 I=I1,N
      DO 90 J2=J1,N2
   90 B(I,J2) = B(I,J2)-B(I,K1)*B(K1,J2)
  100 B(I,J1-1) = 0.
      K1 = K1+1
      I1 = I1+1
      J1 = J1+1
  110 CONTINUE
C
C          DIVIDE BY LAST PIVOT ELEMENT IN LAST ROW
C
      IF(B(N,N).EQ.0.)  GO TO 130
      T = B(N,N)
      DO 120 I=N,N2
  120 B(N,I) = B(N,I)/T
      GO TO 140
```

```
C
  130 NSOL = 1
      RETURN
C
C          INTRODUCE ZEROS ABOVE DIAGONAL
C
  140 DO 150 I=1,NM1
      I1 = N-I+1
      NK = I1-1
      DO 150 J=1,NK
      J1 = I1-J
      T = B(J1,I1)
      DO 150 K=1,N2
      B(J1,K) = B(J1,K)-T*B(I1,K)
  150 CONTINUE
C
C          STORE INVERSE IN AI
C
      DO 160 I=1,N
      DO 160 J=1,N
      JN = J+N
  160 AI(I,J) = B(I,JN)
      RETURN
      END



C     EXAMPLE 1
C
      SUBROUTINE  WEVMOD (N,U,W,V)
      DIMENSION  U(10), W(10,10), V(10), A(12)
      A(1) = 0.5/((U(1)+U(2))**2)
      A(2) = 20./(U(3)*U(3))
      A(3) = 0.1538*U(2)*U(2)+0.5483*(U(2)+U(3))+0.0769*U(2)*U(3)
      A(3) = 1./A(3)
      A(4) = 0.1538*U(3)*U(3)+0.5483*(U(2)+U(3))+0.0769*U(2)*U(3)
      A(4) = 1./A(4)
      A(5) = 0.0556*(U(1)+U(2))**2+0.0278*(U(1)+U(2))*(U(1)+0.5*U(3))
      A(5) = 1./A(5)
      A(6) = 0.0556*(U(1)+0.5*U(3))**2+0.0278*(U(1)+U(2))
     X          *(U(1)+0.5*U(3))
      A(6) = 1./A(6)
      A(7) = 3.5/((U(2)+U(3))**2)
      A(8) = 3.5/((2.*U(1)+2.*U(2))**2)
      A(9) = 3.5/((2.*U(1)+U(2)+0.5*U(3))**2)
      A(10) = 3.5/((2.*U(1)+U(2)+U(3))**2)
      A(11) = 3.5/((2.*U(1)+1.5*U(3))**2)
      A(12) = 3.5/((2.*U(1)+U(2)+0.5*U(3))**2)
      W(1,1) = A(1)+A(5)+A(6)+4.*A(8)+4.*A(9)+4.*A(10)+4.*A(11)+4.*A(12)
      W(1,2) = A(1)+A(5)+4.*A(8)+2.*A(9)+2.*A(10)+2.*A(12)
      W(1,3) = 0.5*A(6)+A(9)+2.*A(10)+3.*A(11)+A(12)
      W(2,2) = A(1)+A(3)+A(5)+A(7)+4.*A(8)+A(9)+A(10)+A(12)
      W(2,3) = A(7)+0.5*A(9)+A(10)+0.5*A(12)
      W(3,3) = A(2)+A(4)+0.25*A(6)+A(7)+0.25*A(9)+A(10)+2.25*A(11)
     X          +0.25*A(12)
      DO 10 I=1,N
      DO 10 J=I,N
   10 W(J,I) = W(I,J)
```

```
 V(1)    = 15.8705*A(1)+7.3294*A(5)+9.789*A(6)+38.6702*A(8)
X         +42.4582*A(9)+25.3014*A(10)+26.7880*A(11)+24.4916*A(12)
 V(2)    = 15.8705*A(1)+2.8561*A(3)+7.3294*A(5)+4.0947*A(7)
X         +38.6702*A(8)+21.2291*A(9)+12.6507*A(10)+12.2458*A(12)
 V(3)    = 7.096*A(2)  +0.6724*A(4)+4.8945*A(6)+4.0947*A(7)
X         +10.6146*A(9)+12.6507*A(10)+20.0913*A(11)+6.1229*A(12)
 RETURN
 END
```

NUCLEAR REACTORS

NUCLEAR REACTORS BUILT, BEING BUILT, OR PLANNED IN THE UNITED STATES AS OF DEC. 31, 1976.

This compilation contains current information about facilities built, being built, or planned in the United States for domestic use or export which are capable of sustaining a nuclear chain reaction. Civilian, production, and military reactors are listed, as are reactors for export and critical assembly facilities.

Revisions are published twice a year, and the information presented is current as of June 30 or December 31.

The publication (44 pages, 8 x 10½, paperback) is available as TID-8200-R35 for $3.25 from National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

INDEX OF ARTICLES (1972-1977)

Dennis M. Bishop, "New Scope and Goals for N-15 Subcommittee INMM-9 (Nondestructive Assay)," 26-39.

John L. Jaech, "Some Thoughts on Bias Corrections," 40-44.

Vol. IV, No. 4, Winter 1976

Thomas J. Haycock, Jr., "Nuclear Materials Information System (NMIS)," 31-37.

John L. Jaech, "Errors of Measurement with More Than Two Measurement Methods," 38-41.

John P. Stewart, "A System of Accountability and Quality Fuel Rod Scanning in a Fuel Fabrication Facility," 42-47.

Kirkland B. Stewart, "Optimizing the Use of Bias Corrections in Minimizing the Variance of MUF," 48-53.

David W. Zeff, "Bias Battle," 54-55.

Vol. V, No. 1, Spring 1976

Dennis M. Bishop, "Nondestructive Assay Measurement Traceability: The Burden of Proof," 16-27.

Ronald H. Augustson et al. "The LASL-U.S. ERDA Nondestructive Assay Training Program," 28-32.

Samuel M. Zivi and W.B. Seefeldt, "Temporal Response Methods for Dynamic Measurement of In-Process Inventory of Dissolved Nuclear Materials," 33-46.

Louis W. Doher, "INMM-8 Pilot Program," 47.

A. Lee Harkness, "Measurements, Biases and Uncertainties," 48-51.

Kirkland B. Stewart, "A Note on Biased Bias Estimate," 52-54.

George H. Winslow, "Some Statistical Aspects of the Calibration and Use of Linear Measuring Systems," 55-59.

Vol. V, No. 2, Summer 1976

Carleton D. Bingham, H. Thomas Yolken, William P. Reed, "Nondestructive Assay Measurements Can Be Traceable," 32-35.

V.W. Lowe, M.S. Waterman, "On the Variance of a Product with Application to Uranium Estimation," 36-41.

R.L. Dickeman, "Safeguards Perspectives an Expression of Industry's Responsibilities and Views," 42-46.

M. Baston, E.A. DeVer, T.C. Bishop, "Proposed Real-Time Data Processing System to Control Source and Special Nuclear Material (SS) at Mound Laboratory, 47-53.

John L. Jaech, "Rounding Errors in Weighing," 54-57.

J.L. Parker, T.D. Reilly, "Transmission Measurement Correction for Self-Attenuation in Gamma-Ray Assays of Special Nuclear Materials," 58-67.

Vol. V, No. 4, Winter 1976-1977

John P. Stewart, "A Modular Enrichment Measurement System for In-Situ Enrichment Assay," 21-25.

George H. Winslow, "A Problem Related to Grubbs Technique: The Distribution of Method Variance Estimates for Known Product Variance," 26-29.

Donald A. Close, "A Gamma-Ray Perimeter Alarm System," 32-38.

Pyrtle W. Seabaugh et al., "A Controllable Unit Concept as Applied to a Hypothetical Tritium Process," 39-48.

Editor's Note: Vol, 1, No. 3, Vol. II, No. 3, Vol. III, No. 3, Vol. IV, No. 3, and Vol. V, No. 3 are proceedings of annual meetings of INMM. Copies of the tables of contents for those proceedings are available on written request to the editors.

Molen

INMM'S Program Chairman

Since 1971, **Garrel F. (Gary) Molen** has worked with Allied-General Nuclear Services (AGNS) in the plutonium processing and safeguards fields. A chemist by training, Molen is presently manager of AGNS' Nuclear Materials Safeguards Department.

In this position, he is primarily responsible for the development and implementation of a program to safeguard special nuclear materials, SNM accounting and control, and to coordinate these efforts with the areas of physical and technical security in order to have a comprehensive safeguards program.

Safeguarding special nuclear materials is, of course, a pivotal issue in the government's current deliberations on the licensing of nuclear fuel reprocessing facilities. To this end, Molen's chief task lies in assuring that AGNS' program for safeguarding SNM will meet the NRC and/or IAEA requirements.

Well prepared for this assignment, the chemist began his career in 1958 when he elected to major in chemistry and math at Illinois College. After earning an M.S. in chemistry from Southern Illinois University, Molen accepted a position with Dow Chemical in 1963.

From 1963 to 1970, he worked in various chemistry-related disciplines, holding positions of increasing responsibility at Dow Chemical Company, then at United Nuclear Corporation. In 1970, he joined the staff of Allied Chemical Corporation as a nuclear process chemist, and within a year was transferred to the nuclear fuel reprocessing facility in Barnwell, S. C. which Allied Chemical Corporation owns jointly with General Atomic Company.

In addition to his responsibilities at AGNS, Molen also finds time to speak at nuclear conferences across the country. His topics have included "The Safeguards Program for the BNFP," "Safeguarding Plutonium in a Reprocessing Plant," and "Implementation of Fuel Cycle Safeguards."

Of his involvement in nuclear reprocessing, he says, "I have always believed that nuclear power is the key to the nation's energy needs, especially its short term needs. Other forms of energy are important and should be developed," he says, "but they don't have the current potential that nuclear energy has."

Molen is a member of the American Chemical Society and the Institute. He and his wife Sara have two children, a son, Kevin, and a daughter, Michelle.

ASSESSMENT OF DOMESTIC SAFEGUARDS FOR LOW-ENRICHED URANIUM

SPECIAL INMM REPORT

AD HOC WRITING GROUP OF THE
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X-RAY REAL TIME IMAGING

Pensacola, Florida—A new X-ray real time imaging system designed by Science Applications, Inc., of LaJolla, Calif., proved successful in extensive on-site demonstrations here recently at the Naval Air Rework Facility (NARF).

"Application of this new technique resulted in immediate visual presentation of hidden flaws in various components," said **M.J. Devine,** director, Analytical Rework Program Office, Naval Air Development Center (NADC), Warminster, Pa., sponsor of the new technology program.

"By viewing X-ray pictures on a videomonitor," Devine said, "the time consuming steps involved in handling X-ray film and film processing were eliminated. Technological advancements present in this new system also represent a substantial reduction in both cost and man hours which have long been associated with X-ray inspection.

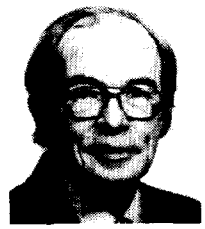
Also," he said, "the system will allow us, by electronic transmission, to have various experts at remote NARF locations examine the pictures simultaneously."

Under Devine's leadership, NADC's demonstration of the Science Applications, Inc., system was conducted for the Naval Air Systems Command, Washington, D.C. "This program, along with others," Devine said, "represents the major goal of NADC for rapid utilization of high technology to reduce life cycle costs and increase equipment reliability."

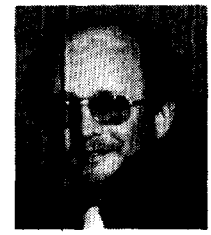
The prototype unit, developed and fabricated by Science Applications, Inc., includes improvements in resolution, contrast sensitivity, portability and cost compared to present commercial systems, according to Dr. **Victor Orphan,** manager, Radiation Applications Division, Science Applications, Inc.

"Since we demonstrated the prototype in Pensacola," Dr. Orphan said, "there has been an accelerated interest in the technique from both the military and commercial sectors." Highlights of this work will be presented at the American Society for Nondestructive Testing Conference on "Innovative and Advanced NDT Radiography," Aug. 2-4, Brandywine Hilton Hotel, Wilmington, Del.


Bishop


Harkness


Jaech


Kraft


Wilson

ABOUT THE AUTHORS

Dennis M. Bishop (B.S., Metallurgical Engineering, Calif. St. Poly. Univ.; M.B.A., Business, Univ. of Santa Clara) is a Senior Engineer in the Nuclear Materials Safeguards Assurance group with the General Electric Company, San Jose, California. His responsibilities include assuring the technical adequacy of measurement and statistical control systems used for the management of special nuclear materials throughout the Nuclear Energy Division. Mr. Bishop's previous experience includes plutonium fuel fabrication process development and irradiation testing, and the development of safeguards and nondestructive assay systems for both uranium and plutonium fuels. Mr. Bishop is a member of the INMM and is Chairman of N15 Subcommittee INMM-9 (Nondestructive Assay).

A. Lee Harkness (M.Sc., McMaster University) is a member of the Nondestructive Assay Section of the Special Materials Division at Argonne National Laboratory, where he is active in the application of statistical procedures to measurement data and other material control and safeguards problems.

John L. Jaech (M.S., Mathematical Statistics, University of Washington) is a Staff Consultant in statistics for the Exxon Nuclear Company, Richland, Wash. This year he became Chairman of the ANSI N-15 Standards Committee of the INMM. A statistical consultant in the nuclear field for more than 20 years, Jaech had been Chairman of the INMM-sponsored ANSI Subcommittee on Statistics. He has authored 16 open literature publications on statistical methods and applications in various journals.

Anton Kraft (M.A. Mathematics, University of Montana, 1965) is a staff member of Exxon Nuclear Company, Richland, Washington. He is a member of Subcommittee INMM-6, Inventory Techniques. His main activity is in the area of system design in nuclear material control and accountability.

Dennis W. Wilson (B.S., Chemical Engineering, University of Utah, 1962); manager, nuclear material safeguards systems, General Electric Nuclear Division, San Jose, Calif. His duties are to define safeguards systems used through the GE's energy divisions to safeguard nuclear materials. He is chairman of the INMM Safeguards Committee and directed the recent INMM special study on "Assessment of Domestic Safeguards for Low-Enriched Uranium."

PATENT TO UMBARGER. . .

An INMM member, **C. John Umbarger** and a colleague Leo R. Cowder, at Los Alamos, (N. Mex.) Scientific Laboratory, were granted U.S. Patent 3,988,615 on Oct. 26, 1976 for a method of radioactivity monitoring.

The invention relates in particular to monitoring for uranium and thorium content in liquid effluents placed on a sample counting chamber. One object of the invention is to provide economical on site monitoring capability. Another object is to provide detectability as low as 10 nanocuries per gram using a portable detector for transuranic solid bulk wastes.

The above information appeared on p. 15 of the March 1977 issue of **The Atom** at LASL.