THIRD ISSUE — CONTENTS

INMM

NUCLEAR MATERIALS MANAGEMENT

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JOURNAL OF THE INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

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Editorials

Dr. Curtis G. Chezem

MBA-99

It's probably not a good idea to attempt to write an editorial while the sole occupant of an Amtrak Parlor Club Car clicking through a countryside stripped for winter. Like that other contemporary philosopher, Charlie Brown, I tend to fall asleep. Perhaps the sleep is merciful.

We've just attended a meeting. It could have been any society's function and we can say all the things about this one that we have been saying for over 20 years. Never before, however, have we been subjected to so many complaints as in the last few months. Let's face up to it . . . the "high rent" mass palaces are decaying and our fellow troops don't like it.

Overheard recently:

"I have to wash the cockroaches out of the drinking glasses before I can get a drink!"

"I can't go barefoot in my room, there are little stones or something all over the floor . . . they must never vacuum."

"Curt, step into my bathroom, you've got to see it to believe it, my tub is full of plaster that dropped off the ceiling."

"I haven't seen any cockroaches, just those other little black bugs!"

"Man it was a good hike up here . . . eight floors . . . well, it's good for me . . . the elevators still don't work."

"The elevators work on our end of the building, it's just faster to walk except those narrow stairs are so crowded!"

"Anybody found a good place to eat?" ". . . only if you wanna take a cab out of town."

"How much is your room . . . good grief! Oh, well, your company can afford it." "That's **not** the point!"

So we doff our hats to the INMM executive committee and the meeting site selection group for the first step in getting out of the ruts.

We speed on through cities and towns, nuns and cans mark the waterways to our right. An airport beacon flashes against the low clouds. It could snow tonight. Amtrak has the last three stations within 30 seconds of schedule. Two little kids just waved at the train. The world seems to be in reasonable working order. I'll recline the seat . . . move over Charlie Brown. — C.G.C.

THE CHAIRMAN SPEAKS

Harley L. Toy

STATUS '73

As we enter the new year I am further convinced of the positive, beneficial role the Institute is demonstrating in tangible services to the membership and the industry. In assessing services to the membership one merely points to the caliber and timely technical articles carried in the first three issues of our Journal. According to "Tom the Man," our managing editor of the Journal, highly qualified authors are now emerging and most anxious to publish their studies. This, I feel, is a true gauge of the overall acceptance of the Journal as the professional voice in Nuclear Materials Management.

In the area of service to the industry, especially standards activities, I think it is safe to say "the-jury-is-in" on our contributions to date. Bob Delnay, Chairman of N15 will elaborate further on this subject later in this issue. However, it is most significant to note at this point, that the recently published **USAEC Regulatory Guide Series** listed Regulatory Guide 5.2, "Classification of Unirradiated Plutonium and Uranium Scrap." As stated by Mr. Lester Rogers, Director of Regulatory Standards, the Division 5 series of guides is being developed specifically to provide guidance on the acceptability of materials-protection-related features of nuclear facilities licensed to possess special nuclear material. Other N15 generated standards currently under development for inclusion in the Division 5 series include:

* Nuclear Materials Control Systems and Procedures for Conversion Facilities.
* Statistical Terminology and Notation Guide for Nuclear Materials Management.
* Analytical Standards for the Measurement of Uranium Tetrafluoride (UF_4) and Uranium Hexafluoride (UF_6).

It goes without saying that the Institute is playing a vital role in assisting industry in the ever increasing area of standards development.

Your Executive Committee held its first meeting of FY 73 in late September in Bethesda. The first item of business was the selection and appointment of Standing Committee Chairmanships. The Executive Committee confirmed the following Committees and respective Chairmen for FY 73:

* Program Committee - R. G. Cardwell.
* N15 Standards Committee - R. L. Delnay.
* Government Relations and Standards Coordinator - F. Forscher.
* Public Relations - V. J. DeVito.
* Materials Protection Committee - Lou Strom.
* Institute Manual - Ron Damm.
* Certification and Professional Standards Committee - W. D. McCluen.
* Membership Committee - R. L. Jackson.

It is indeed a pleasure to work with such a team. Each of the above Chairmen have proven know-how in their respective assignments.

Our "tight-fisted" Treasurer, Ralph Jones reports that there is no fear of foreclosure and that our financial house is in order. Mr. Joseph V. Catania, Auditor, performed an audit of our financial records for the period July 1, 1971, to June 30, 1972. The results of Mr. Catania's audit along with the accompanying financial statements are presented in another section of the Journal.

One of the highlights of our meeting was the opportunity to meet with Mr. Jim Powers, Chief of the Materials Protection Standards Branch, of the Directorate of Regulatory Standards. We invited Jim to our meeting to discuss just "how and where" the Institute might interface with the Materials Protection Branch. Jim emphasized that the current atmosphere within the Regulatory Directorate is one of urgency in the development of nuclear standards. He discussed the role of N15 relative to specific tasks responsive to the charter of the Materials Protection Branch. Within this framework he referred to the current cooperation between the AEC and ANSI in expediting the development of guides and standards. One of the immediate tasks of his branch is the publication of guides relating to acceptable materials protection methods. I am happy to add that Jim will be preparing an article for the April issue of the Journal in which he will discuss the role of the Materials Protection Branch in terms of scope, goals, and future direction.

Following our Executive Committee Meeting, I contacted Jim and advised him formally of the INMM Certification Program and how we might interface and assist in the implementation of the Commission's Materials Protection Program. Jim responded favorably to our proposal pointing out that highly qualified technical and managerial licensee personnel are essential to the establishment and enactment of a material protection program meeting Regulatory requirements. At this stage we have agreed to a joint meeting whereby an exchange of views could be debated and specific areas of our Certification Program could be discussed in detail.

We shall keep you advised of progress and report in detail on the results of our meeting. Needless to say, the Institute will be well represented at such a meeting, especially members of our Certification Board.

In closing I would like to turn back to "service to the industry" which I referred to at the outset. Certainly standards activities, especially those standards and guides aimed at regulatory requirements are an essential and represent **in part** the objectives and purpose of our organization. However, let us not lose sight of the economic aspects in Nuclear Materials Management calling for efficiency and in-depth managerial decisions which are mandatory for sustained existence in this day-to-day nuclear business. Government imposed regulations in the nuclear community as we would all agree—possibly more stringent and comprehensive during the past few years—are a way of life. Once again, however, are the two requirements totally incompatible? I am quite aware that this question is "old hat" to many, but I am sure some will come out of their chair at such a question. I invite your comments on this question. More on this in the next issue. To all a most prosperous New Year. — **Harley L. Toy**

AUDITOR'S REPORT

September 17, 1972

Executive Committee
Institute of Nuclear Materials Management

Gentlemen:

I have examined the Statement of Cash Receipts, Disbursements, and Income submitted by the Treasurer of the Institute of Nuclear Materials Management for the period July 1, 1971 to June 30, 1972. The examination was made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records as were necessary in the circumstances.

In my opinion, the accompanying Statement of Cash Receipts, Disbursements, and Income presents fairly the financial position of the Institute at June 30, 1972, and reflects the results of the Institute's operation for the period then ended in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

Yours truly,

Joseph V. Catania, Auditor

Letters To the Editor

The following exchange of correspondence among the Editor of Nuclear Materials Management, the managing editor, ex-president Lovett, R. L. Jackson, Editor of the Newsletter and H. W. Norton may be classified as closing out old business. The original set of correspondence is either still in one of some fifteen boxes of books and papers somewhere between Kansas and New Orleans or was inadvertently misplaced. H. W. Norton is a Professor of Statistical Design and Analysis in the Department of Animal Science at the University of Illinois.

Gerdis from Norton, September 8, 1972:

". . . I judge that the enclosed correspondence may have been misdirected to Mr. Chezem, and should have been sent to you. Please be good enough to let me know whether this material reaches you."

Chezem from Norton, May 13, 1972:

"The May 1971 INMM Newsletter claimed (p. 2) to be 'an excellent means of forum for members to express their views on the current or projected nuclear scene. Any member is free to write anything, expressing any opinion — we are anxious to have independent viewpoints.' My impression is that the quoted statement was rather unproductive.

"Volume 1 Number 1 of Nuclear Materials Management, which I found interesting and attractive, says that letters to the editor will start next issue. Therefore a copy of my letter commenting on an item in the September Newsletter is enclosed, as are copies of Mr. Lovett's reply and my response to him, all unpublished. Perhaps you will see fit to use them in an early issue of NMM, though you may prefer not to publish comment referring to the Newsletter.

"In reading this correspondence, it may occur to you that some views are **too** independent. If you have occasion to write to me, a statement of your position in that respect would be most welcome."

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT STATEMENT OF CASH RECEIPTS* DISBURSEMENTS* AND INCOME FOR THE YEAR ENDED JUNE 30, 1972

Cash Balance - July 1, 1971			
Savings Account			
Home Savings & Loan Assn.		$10261.41	
San Francisco, Cal.			
Checking Account			
Suburban Trust Co.			
Hyattsville, Maryland		4626.30	14887.71
Receipts			
Dues - Renewals	$4380.00		
- New Members	825.00	$ 5205.00	
Annual Meeting		9212.48	
Sale of Proceedings		615.00	
Exhibitors' Fees		675.00	
Certified Nuclear Materials Manager Fees		125.00	
Interest Income		709.53	
Journal and Advertising Subscriptions		421.50	
Total Receipts			16963.51
			$31851.22
Disbursements			
Stationery and Supplies		$ 503.74	
INMM News Letter - Printing		1016.04	
INMM News Letter - Postage		513.19	
INMM Manual - Postage		10.92	
INMM Journal - Editor		1400.00	
INMM Journal - Printing		517.54	
INMM Journal - Postage and Miscellaneous		220.38	
General Postage		336.94	
Standards Committee Expenses		155.13	
INMM Committee Expenses		334.06	
Executive Committee Expenses		143.65	
Annual Meeting Expenses		12375.52	
Certified Nuclear Materials Manager Expenses		39.05	
Total Disbursements			$17566.16
Cash Balance - June 30, 1972			
Savings Account - Home Savings & Loan Assn.		$11470.94	
Checking Account - Suburban Trust Co.		2814.12	$14285.06
Loss For Period Ended June 30, 1972			$16963.51
Receipts			17566.16
Disbursements			
Net Loss			$ 602.65

Institute of Nuclear Materials Management Statement of Income and Expenses Thirteenth Annual Meeting Boston, Massachusetts May 31 - June 2, 1972

INCOME

Registration	$4169.00
Banquet	2060.00
	6229.00

EXPENSES

Pre-registration Package	$ 393.92
Agenda	1207.77
Banquet	2216.44
Speakers Breakfast	160.93
Ladies' Program	166.79
Coffee Breaks	443.70
Reception	150.89
Miscellaneous	129.80
	$4870.24
Net Income	$1358.76

Jackson from Norton (enclosed with Chezem from Norton), September 7, 1972:

"One comment seems necessary on the letter from Dr. Lovett to Dr. Thornton published in the September INMM Newsletter. I refer primarily to the paragraph on inventory frequency versus accuracy.

"Lovett says 'We believe . . . that this need for accuracy has been confused with a need for more rapid timing.' I cannot speak for Dr. Thornton, but I doubt that he confuses these two. Lovett nowhere in his letter gives any indication of appreciating the need for **prompt** detection, which is of first importance if detection is to be useful. Without promptness, detection will be of only historical interest. Lovett says that an example cited by Thornton 'achieved less than a three-fold reduction in the total material balance uncertainty, at a twelve-fold increase in inventory cost,' a statement that suggests an intention to de-emphasize the example. How easy it would have been to say instead that, while achieving the three-fold reduction, detection (of sufficiently large diversions) would be six months earlier on the average, sooner still if the diverter was acquainted with the frequency and timing of the annual inventory, and to then offer some opinion of the value (as distinct from the more repellent term 'cost') of these gains.

"By the way, are the values 136 Kgs and 171 Kgs, for uncertainties based respectively on annual and monthly inventories, relatively correct? Has someone found a way to increase the uncertainty by more frequent inventories?"

Norton from Lovett (also enclosed), September 16, 1971:

"Thank you very much for your September 7 letter commenting on the INMM's response to the AEC concerning inventory frequency requirements. Basically, it is my position that when one speaks of prompt detection requirements in the context of material balance accounting systems, he is asking material balance accounting to accomplish something which it was never designed to do and which it in general cannot do with any significant efficiency. If your house is robbed, it is unimportant whether you discover that fact one month later or six months later. Your chances of catching the robber decrease very rapidly in the first few hours after the event, and indeed your chances are significant only if you can catch the robber while he is still on the premises. Thus so far as prompt detection is concerned, I advocate significant increases in both personnel and physical security. Radiation monitoring devices are available which are capable of detecting any attempted theft of even a few grams of fissile material. For that matter, those quantities of fissile material which are of practical significance in a safeguards context would be difficult to conceal on one's person, and probably could be detected by a good system of guards. Also, the AEC has been advised by several groups that all persons in the nuclear industry should be required to have an L clearance. I understand but cannot sympathize with the legal problems which have led the AEC not to adopt this requirement. Until an adequate system of personnel security is adopted, the entire nuclear materials safeguards effort remains highly debatable.

"I also believe that there is a class of potential divertors, usually characterized by reference to the non-weapon State, which must be presumed to have the resources to gain access to nuclear material, to carry out a subtle, long-range diversion scheme, and to convert their diverted material into a usable nuclear weapon. This group cannot be stopped by security measures, and they must be stopped by material balance accounting systems. Accordingly it is here that I advocate more accurate but not necessarily more frequent material balances. I am fully prepared to invest the cost of 12 monthly inventories in 3 or 4 really good inventories, capable of contributing meaningful information concerning the probability that a subtle long-term diversion scheme is being implemented.

"In response to your comment concerning the larger uncertainty associated with monthly inventories, I have derived that result by assuming that each material balance period was examined separately. In this way each of the 11 intermediate inventories also contributed an uncertainty to the total MUF across the 12 month period. Obviously, other statistical techniques could be employed to evaluate the cumulative MUF, or to evaluate some form of running average MUF, thereby reducing the uncertainty associated with monthly inventories. I believe that there is a practical problem, however, in that there will be some reluctance to accept the results of complex statistical techniques at their full face value. To whatever extent statistical data is not believed, its effectiveness is lost.

"Again thank you for your comments. I would be happy to discuss this subject further with you sometime if we can manage to get together."

Lovett from Norton (also enclosed), September 28, 1971:

"Thank you for your unexpected response to my letter to the editor of the INMM Newsletter. You may be right that material balance accounting 'was never designed' to achieve prompt detection. Many would agree, and some of us assert that it should be so designed. Also you may be right in thinking that material balance accounting cannot achieve prompt detection 'with any significant efficiency.' Many would agree that it does not now do so, but 'prompt' and 'significant efficiency' certainly leave plenty of room for disagreement.

"Physical security, though indispensable, is neither adequate by itself nor is it capable of prompt detection in the really important case in which security personnel are involved. Physical security unsupported by effective material balance accounting gives only the illusion of control.

"It is not clear to me what you mean by saying 'I am perfectly willing to invest the cost of 12 monthly inventories in 3 or 4 really good inventories, capable of contributing meaningful information . . . 'I cannot help thinking that statement is associated somehow with your calculation of a larger uncertainty for more frequent material balances, and I sincerely hope that you will do nothing more to detract from the acceptability and effectiveness of statistical analysis. The idea of advocating monthly inventories was that they should be 'good' and that they would contribute 'meaningful information.' Of course, whether monthly inventories would accomplish quicker detection of diversion (whether subtle or not) would be determined by the effort put into them as compared to that which would be expended on less frequent inventories."

Editor's Note: We have been challenged for a response in the area of our attitude toward the statement ". . . that some views are **too** independent." We suspect the learned professor means by "**too** independent" only that the view is a radical departure from what is assumed to be accepted or established. Any view must find acceptance on the market place of ideas to gain respect and value.

One of my most satisfying academic experiences was to assign my students some outside reading of work by Rutherford or Michelson in the original journal of publication. Besides being a fascinating experience, the student is impressed by the great mass of ideas that didn't make it on the market place of truth.

My point is that we must provide a vehicle for public scrutiny of ideas if we are to maintain professionalism in our journal. Or, as they say, let's run it up the flagpole and see if it flies!

Dear Editor:

The second issue of the Journal came. I think it looks great. I hope Curt's (Curtis G. Chezem, Editor of NUCLEAR MATERIALS MANAGEMENT, Journal of INMM) leaving Kansas State University doesn't mean that we will soon have to look for a new Editor.

I doubt very much if there will be any more of my series of articles on management philosophy. If I have time and can get motivated, I will try to write one more before I leave.

James E. Lovett
Past Chairman, INMM
Export, Pa.

Editor's Note: Mr. Lovett's comments regarding the Journal are gratefully received. This past summer he resigned from his position at Nuclear Materials and Equipment Corp., Apollo, Pa. In October,

he joined the International Atomic Energy Agency, Vienna, Austria.

Dr. Chezem, Manager of Nuclear Activities for Middle South Services, Inc., New Orleans, La., continues as Editor of the Journal. Until July 17, he had been Black & Veatch Professor and head of nuclear engineering at Kansas State University, Manhattan, before accepting his challenging new position. Prior to that, he was a branch chief with the USAEC.

Robert L. Delnay

A.N.S.I. Standards Report

By R. L. (Bob) DELNAY
Chairman
ANSI, N15

N15.6-1972 — "Accountability of Uranium Hexafluoride, Analytical Standards For"
This standard was published in October and is now available from the American National Standards Institute.

N15.8 — "Nuclear Materials Control Systems for Nuclear Power Reactors, A Guide to Practice"
The letter ballot is complete. There are three negative ballots which will require extensive revisions to the proposed standard. The proposed standard will be re-submitted for letter ballot after all revisions have been made.

N15.9 — "Nuclear Materials Control Systems for Fuel Fabrication Plants, A Guide to Practice"
The letter ballot is complete. There are a few minor comments to be resolved. The proposed standard probably will not require another letter ballot.

N15.10-1972 — "Classification of Unirradiated Plutonium Scrap"
Board of Standards Review approved this standard on July 25, 1972.

N15.11 — "Auditing Nuclear Materials Statements"
The letter ballot is complete. There were only a few minor comments which will be incorporated into the proposed standard. The proposed standard will be submitted to ANSI for public review and approved by the end of this year.

N15.13 — "Nuclear Material Control System for Irradiated Fuel Processing Facilities"
The proposed standard is in N15 letter ballot.

N15.15 — "Assessment of the Assumption of Normality"
The proposed standard will be ready for N15 letter ballot by January, 1973.

NEWS

High-Speed Fuel Rod Scanner

Gulf Radiation Technology (Rad Tech), Box 608, San Diego, CA 92112, recently completed the first production model of the Gulf High-Speed Fuel Rod Scanner. The scanner is designed for high-precision, high-speed measurement of individual rogue UO_2 fuel pellets in assembled fuel rods, as well as measurement of the total fissile content of each rod.

It was also announced that the Californium Demonstration Center, established jointly by the USAEC and Rad Tech on June 5, is now in operation, and loan applications for Cf-252 sources are being processed.

Over 50 mg of Cf-252, supplied by the AEC, are presently in the Center at the Gulf of La Jolla facilities. A total of 100 mg, valued at 1 million, will be supplied to the Center.

Research programs for universities, the aerospace industry, and the services available there can be obtained from Dr. Joseph John at Rad Tech (714 453-1000, Ext. 17-332).

Second Edition of Book Announced

An old standby for Nuclear Materials Managers has a new look. A second edition of Selected Measurement Methods for Plutonium and Uranium In The Nuclear Fuel Cycle has just been published by the USAEC. The first edition published in 1963 and edited by Ralph J. Jones, INMM treasurer, had become a standard in essentially all nuclear chemistry laboratories. The second edition, published in the spring of 1972, was edited by Clement J. Rodden, former director of the USAEC New Brunswick Laboratory. In his preface to the second edition Mr. Rodden says:

"The present emphasis on the safeguarding of fissionable materials has resulted in renewed interest in methods for the determination of chemical and isotopic uranium and plutonium. Since the interest at present is in the fuel cycle of fissionable materials, the revised edition has been reorganized to indicate methods of analysis for materials starting with the product material used in the preparation of nuclear fuels through the products obtained from the recovery of fissionable materials from irradiated fuels."

The second edition is available from the National Technical Information Service, U.S. Dept. of Commerce, Springfield, Virginia 22151. Price is $6.

Second Annual Basic Course in Active Techniques

San Diego, Calif. — Gulf Rad Tech will teach a four-day basic course in the latest state-of-the-art nondestructive assay techniques, using isotopic sources, in San Diego Feb. 5-8. This course is designed to give safeguards, nuclear materials management, or quality control personnel, and others interested in assay or control of SS materials, a basic working knowledge of proven, practical active assay techniques which can be implemented in the average laboratory or manufacturing plant. Contact William J. Gallagher, 714-453-1000, Ext. 17-356.

Need Addresses

The INMM Publications Office (18 Seaton Hall (EES), KSU, Manhattan, KS 66506) needs addresses for the following four individuals. If you can provide us with new addresses for them, please send them to us. They are Lewis F. Casabona, John L. Curtis, R.P. Dragoo and Roney W. Klemens.

Argonne Short Courses

The following short courses are being offered at Argonne National Laboratory:

Developments in Nuclear Technology — February 26-March 3, 1973. Fee: $400.

Chemical Assay in Nuclear Material Safeguards — March 5-9, 1973. Fee: $400.

Non-Destructive Assay in Nuclear Material Safeguards — March 12-23, 1973. Fee: $800.

Statistical Methods in Nuclear Material Control — March 26-30, 1973. Fee: $400.

Fundamentals of Nuclear Material Control — April 2-6, 1973. Fee: $400.

New Directions in Safeguards — April 9-13, 1973. Fee: $400.

Advanced Statistical Methods in Nuclear

Material Control — May 14-16, 1973. Fee: $160.

Nuclear Materials Safeguards in Power Reactor Operation — May 17-18, 1973. Fee: $160.

Reduced fees are available for employees of governmental organizations, non-profit institutions, AEC cost-type contractors, and university faculty. For applications and further information write to:

Dr. Manuel A. Kanter
Safeguards Training Program
Argonne Center for Educational Affairs
Argonne, IL 60439

New Members

The following individuals have been accepted into INMM membership as of Nov. 15, 1972:

Francis M. Alcorn, Babcock & Wilcox, Lynchburg, Va.; Norman S. Beyer, Argonne National Laboratory, Argonne, Ill.; Ronald W. Brandenburg, Argonne; Richard L. Carlson, General Electric, Morris, Ill.; Donald E. Curran, Federal Power Commission, Washington, D.C.; Barry D. Devine, Arlington, Va.; James B. Edgar, Richland, Wash.; Peter Fried, Brookline Instruments, Elmsford, N.Y.; and J. Russell Hoke II, United Nuclear, Wood River Junction, R.I.

Raymond C. Janks, Kerr-McGee, Crescent, Okla.; Anton Kraft, Richland, Wash.; Ralph T. Lally Jr., Middle South Services, Inc., New Orleans, La.; David A. Lewis, Nuclear Materials and Equipment Corporation, Apollo, Pa.; Edward L. Mahoney, General Electric, Wilmington, N.C.; Theodore S. Michaels, Rockville, Md.; Kenneth R. Osborn, Allied Chemical, Morristown, N.J.; and John W. Pearce, Atomic Energy Attache, Australian Embassy, Washington, D.C.

Robert J. Sorenson, BATTELLE, Richland, Wash.; Jerry F. Staroba, Argonne; Stanley P. Turel, USAEC, Washington, D.C.; and Edgar T. Wein, Commonwealth Edison, Chicago, Ill.

Members accepted after Nov. 15 will be listed in the April 1973 issue of the Journal.

Address Changes of INMM Members

The following are new addresses for members of the Institute of Nuclear Materials Management:

William C. Bartels, Chief, Technical Studies Branch, Division of Nuclear Materials Security, USAEC, Washington, D.C. 20545; Dr. Carl A. Bennett, BATTELLE, Human Affairs Research Center, 4000 N.E. 41st St., Seattle, WA 98105; Leonard M. Brenner, Special Assistant to the Director, Division of Nuclear Materials Security, USAEC, Washington, D.C. 20545; and James R. Clark, Nuclear Fuel Services, 6000 Executive Blvd., Suite 600, Rockville, MD 20852.

Richard A. Cordin, 18 Aurora La., S. Yarmouth, MA 02664; Delmar L. Crowson, Director, Division of Nuclear Materials Security, USAEC, Washington, D.C. 20545; Glenn A. Hammond, Chief, Systems Studies Branch, USAEC, Division of Nucelar Materials Security, Washington, D.C. 20545; George A. Huff, Manager, Analytical and Laboratory Services, Allied-Gulf Nuclear Services, Box 847, Barnwell, SC 29812; and Ralph J. Jones, USAEC, Materials Protection Standards Branch, Directorate of Regulatory Standards, Washington, D.C. 20545.

William B. Kenna, USAEC, 230 Peachtree St., N.W., Suite 818, Atlanta, GA 30303; Allan M. Labowitz, Vienna (MIAA), Department of State, Washington, D.C. 20521; Stephen J. Laycock, Arthur Anderson & Co., 815 Connecticut Ave., N.W., Washington, D.C. 20006; James W. Lee, Transportation Consultant, Box 12601, Lake Park, FL 33403; John W. Loeding, 412 Buckeye Dr., Naperville, IL 60540; and James E. Lovett, International Atomic Energy Agency, Kaerntnerring 11, A-1011, Vienna, Austria.

John F. Mahy Jr., Assistant for International Policy, Division of Nuclear Materials Security, USAEC, Washington, D.C. 20545; Erick L. May Jr., USAEC, Directorate of Regulatory Operations, Washington, D.C. 20545; Dr. Roger H. Moore, 549 Todd Loop, Los Alamos, NM 87544; Emmanuel R. Morgan, 320 Jefferson Ave., N. Plainfield, NJ 07060; P. K. Morrow, Nuclear Fuel Services, 23 E. Main St., Springville, NY 14141; and Walter G. Mosgovoy, Gulf Oil Co., Director, Central European Representation, 7 Astons Rd., Moor Park, Middex, England.

S. G. Nordlinger, 2525 Middle River Dr., Ft. Lauderdale, FL 33305; R. G. Page, Directorate of Licensing, USAEC, Washington, D.C. 20545; R. E. Perrin, 2969-A Walnut St., Los Alamos, NM 87544; Charles N. Smith, USAEC, Directorate of Licensing, Materials & Plant Protection Procedures Branch, Washington, D.C. 20545; and Robert D. Smith, Directorate of Licensing, USAEC, Washington, D.C. 20545;

Dr. C. D. W. Thornton, Special Assistant for Energy Policy, Division of Planning and Analysis, USAEC, Washington, D.C. 20545; James Verme, USAEC, Division of Production & Materials Management, Washington, D.C. 20545; Russell E. Weber, Chief, Reports and Analysis Branch, Division of Nuclear Materials Security, C-110, USAEC, Washington, D.C. 20545; Harold V. Werner, USAEC, Directorate of Regulatory Operations, Washington, D.C. 20545; and James M. Williams, Los Alamos Scientific Laboratory, Box 1663, Los Alamos, NM 87544.

OUT OF CONTEXT

All "out of context" items in this issue are ten years old. They are taken from the proceedings of the third annual meeting of the INMM, May 14-16, 1962, St. Louis, Missouri.

"There have been occasional arguments as could be expected, both with our people within the Commission as well as with industry representatives, but I have learned that in most cases, as one wag put it, 'all an argument seems to prove is that two or more people are present!' " — Ernie Tremmel, 1962.

". . . experience in the complexities of the program, however, has been invaluable. I have now acquired sufficient knowledge to realize I should have gone to Denver — this morning!" — H. J. McAlduff, Jr., St. Louis, 1962.

". . . a flood of requests which I understand is referred to as the drip, dab, bottle, pile or puddle period. . . . many letters were received stating in essence 'during my recent visit with Dr. ___ I noticed a bottle of ___ on his shelf. Dr. ___ stated he had no further need for this material and it is just what we require to further our research on mismatched chromosomes in the Tibetan Yak. . .' " — H. J. McAlduff, 1962.

"The impact of alpha is somehwat involved." — E. A. Eschbach, 1962.

"It is self-evident that an organization cannot increase its profits by simply preparing correct inventory and material balance reports to the AEC or anyone else." — Clarence C. Wilson, 1962.

"S-R differences are fairly complex phenomena." — Ralph Lumb, 1962.

"Improvements in Nuclear Materials Management is a continuous process. . ." — Fred Forscher, 1962.

"The INMM manual defines a Nuclear Materials Manager as 'a person qualified to develop and establish program standards and requirements for a system of Nuclear Materials control. He shall possess the proficiency required to institute detailed procedure and to take such actions as are necessary to create or implement a Nuclear Materials control system.' " — Russ Weber and Shelley Kops, 1962.

"There is a lot to be said about the importance of Fuel Cycle Management in regard to reduction of nuclear power cost." — Ken Duffy, 1962.

"The names, places, dates, and material used in these examples are purely fictitious in order to protect the 'guilty.' " — Clarence C. Wilson, 1962.

Deng

Fenech

Heine

Moore

Shen

Sinclair

ADVERTISING INDEX

AUTHORS FOR THIS ISSUE

Frank A. Costanzi (Ph.D., theoretical physics, Northwestern University) came to Kansas State in June, 1971, to participate in the Diversion Safeguards Program. Prior to his joining K-State he was a member of the Physics Department faculty at the Chicago Circle campus of the University of Illinois. He has worked in the areas of high energy and nuclear physics, as well as safeguards. He is presently at the Regulatory Division of the Atomic Energy Commission.

S. F. Deng (M.S., Mechanical Engineering, University of Iowa, 1964) is an Engineer of the Nuclear Analysis Group involved with the development of core physics and thermal-hydraulic analysis capability within the Southern California Edison Company. He has performed core follow calculations for the San Onofre Nuclear Generating Station, Unit 1, using three-dimensional nodal methods for reactivity follow and fuel management applications.

H. Fenech (M.S. and ScD., Nuclear Engineering, MIT, 1959). He was Assistant and Associate Professor in Nuclear Engineering at the Massachusetts Institute of Technology until 1969 and is now Vice-Chairman for Nuclear Engineering at the University of California at Santa Barbara, and was responsible for the formation of this program. He has been a consultant for the utilities and the reactor manufacturers for the last 10 years and is the author of some 30 papers in fuel management and reactor engineering. He is a Senior Engineer in the Nuclear Analysis Group of the Southern California Edison Company.

William F. Heine (B.S., Physical Science, Nebraska State College, Wayne). He is Manager of Operational Safety and Management, Atomics International, North American Rockwell, Canoga Park, Calif. He has completed two years of full-time graduate study at the University of Nebraska. With AI for 11 years, Mr. Heine is responsible for supervision of the operational health physics, environmental monitoring, effluent control, and other programs.

Robert B. Leachman (Ph.D., Iowa State University) has been at Kansas State University since 1967 as director of the Nuclear Science Laboratories and until 1971 as the head of the Physics Department. He was principal investigator of the NSF-sponsored interdisciplinary research diversion safeguards described in this article. From 1950 to 1967 he was at the Los Alamos Scientific Laboratory working principally on fission research. He was a Guggenheim Fellow at the Nobel Institute in 1955-56 and a Fulbright Fellow at the Niels Bohr Institute in 1962-63.

John D. Moore (A.A., Los Angeles Valley College). He is the Health and Safety Representative of the Operational Safety and Waste Management Unit at Atomics International, North American Rockwell, Canoga Park, Calif. He has been responsible for AI's environmental monitoring program since 1958. More recently, he also assumed responsibility for effluent monitoring and control for all AI facilities.

P. K. Shen (Ph.D., Nuclear Engineering, Kansas State University, 1970). He is currently supervising the Nuclear Engineering, Analysis and Radiological Safety Group in the Nuclear Engineering Section of the Southern California Edison Company. He has direct responsibility in developing Edison's in-house nuclear analysis and design capabilities, core engineering support and radiological analysis of the Company's operating and future nuclear generating stations.

B. D. Sinclair (M.S., Information Science, California Institute of Technology, 1971). He is a member of the Computer Programming and Processing Division of the Southern California Edison Company. He currently provides computer methods support for the Nuclear Analysis Group of the Company.

RAPID ASSESSMENT OF ^{235}U FROM URANIUM FUEL FABRICATION FACILITIES

By W. F. Heine and J. D. Moore
Atomic International Division
North American Rockwell Corporation
Canoga Park, Calif.

A method has been developed which permits rapid assessment of ^{235}U in effluents from uranium fuel fabrication facilities. Gross alpha activity is used as a basis for determining precisely the ^{235}U content in effluents containing uranium of known enrichment and for estimating ^{235}U content in effluents containing uranium of unknown enrichment.

Increased emphasis on the safeguarding of source and special nuclear materials has resulted in the requirement for better inventory control at potential loss pathways from uranium fuel fabrication facilities. A method has been developed which permits rapid assessment of the mass of ^{235}U contained in effluent from such facilities on the basis of alpha activity in the effluent. The method may be applied to cases where there is a known ^{235}U enrichment, or to cases where a number of ^{235}U enrichments have been processed and the enrichment of the uranium in the effluent is unknown. In the latter case, the approximate mass of ^{235}U is determined within an assigned range of error.

Most of the alpha activity in uranium fuel results from the presence of ^{234}U, except for fuels with ^{235}U enrichments of less than 1 percent, in which case the ^{238}U alpha activity predominates. Figure I describes the specific activity by isotope of uranium for fuel of any ^{235}U enrichment, from depleted to highly enriched. These data were obtained from National Bureau of Standards uranium standard isotopic compositions reports.(1) The ratio of ^{234}U to ^{235}U specific activities is reasonably consistent ($\pm$ 30 percent) over the entire range of enrichment, and, as a result, it is possible to estimate the mass of ^{235}U present in a uranium sample of unknown enrichment on the basis of the gross alpha activity of the sample. Precise determinations of ^{235}U may be made for known enrichments by use of the factors described in Figure II. In cases where the processing of fuels of several enrichments has resulted in an unknown enrichment in the effluent, the factors which appear in Table I can be applied to estimate the mass of ^{235}U within an assigned error. If a range of possible enrichments is known, the factor corresponding to that range can be used so that the magnitude of assigned error can be minimized.

The use of this technique can be illustrated by considering examples of potential losses of special nuclear material through the release of liquid effluents from retention tanks to sewage systems. Such effluents are normally sampled and analyzed for radioactivity concentrations prior to release. The purpose of such sampling is usually the requirement for assuring compliance with regulatory standards for radioactivity concentrations in effluents. Samples are prepared for analysis by evaporating an aliquot and depositing the residue on a counting planchet. An alpha radiation counting system, including a scintillation-type or gas flow proportional detector, a scaler-timer, and a high voltage power supply is used for counting the radioactivity in the sample residue. The geometry-efficiency factor for the detector-sample configuration is determined with calibration standards which simulate the configuration of the sample.

In the case of a fuel fabrication facility engaged in processing 5 percent enriched uranium, a sample of liquid effluent containing alpha radioactivity of 100 d / m / ml would indicate the presence in the effluent of 1.0×10^{-6} gm ^{235}U / ml, as indicated by Figure II. Figure II describes factors (f) for converting alpha activity in disintegrations per minute to mass of ^{235}U in grams as a function of ^{235}U enrichment, (d / m) (f) equals grams ^{235}U.

In the case of a facility processing uranium of various enrichments ranging from 0.7 to 93 percent, an effluent sample containing 100 d / m / ml would indicate the presence in the effluent of 7.9×10^{-7} ($\pm$) 30 percent gm ^{235}U / ml, as indicated by Table I. Table I describes factors (f) for converting alpha activity in disintegrations per minute to mass of ^{235}U in grams as a function of **ranges** of ^{235}U enrichment, for use in cases where uranium of unknown, or more than one, enrichment is present in an effluent sample.

The concentration determined by analysis of the sample can be applied to the total volume of the effluent to determine the total mass of ^{235}U. In the case of the effluent containing 5 percent enriched uranium in concentrations of 100 d / m / ml, or 1.0×10^{-6} gm ^{235}U / ml, 1000 gallons of effluent would contain 3.8 gm of ^{235}U.

1. United States Department of Commerce, National Bureau of Standards, "Table of Best Estimate Values, NBS Nos. U-005 through U-930," May 20, 1965.

Figure 1

Uranium Specific Activity as a Function of U^{235} Enrichment

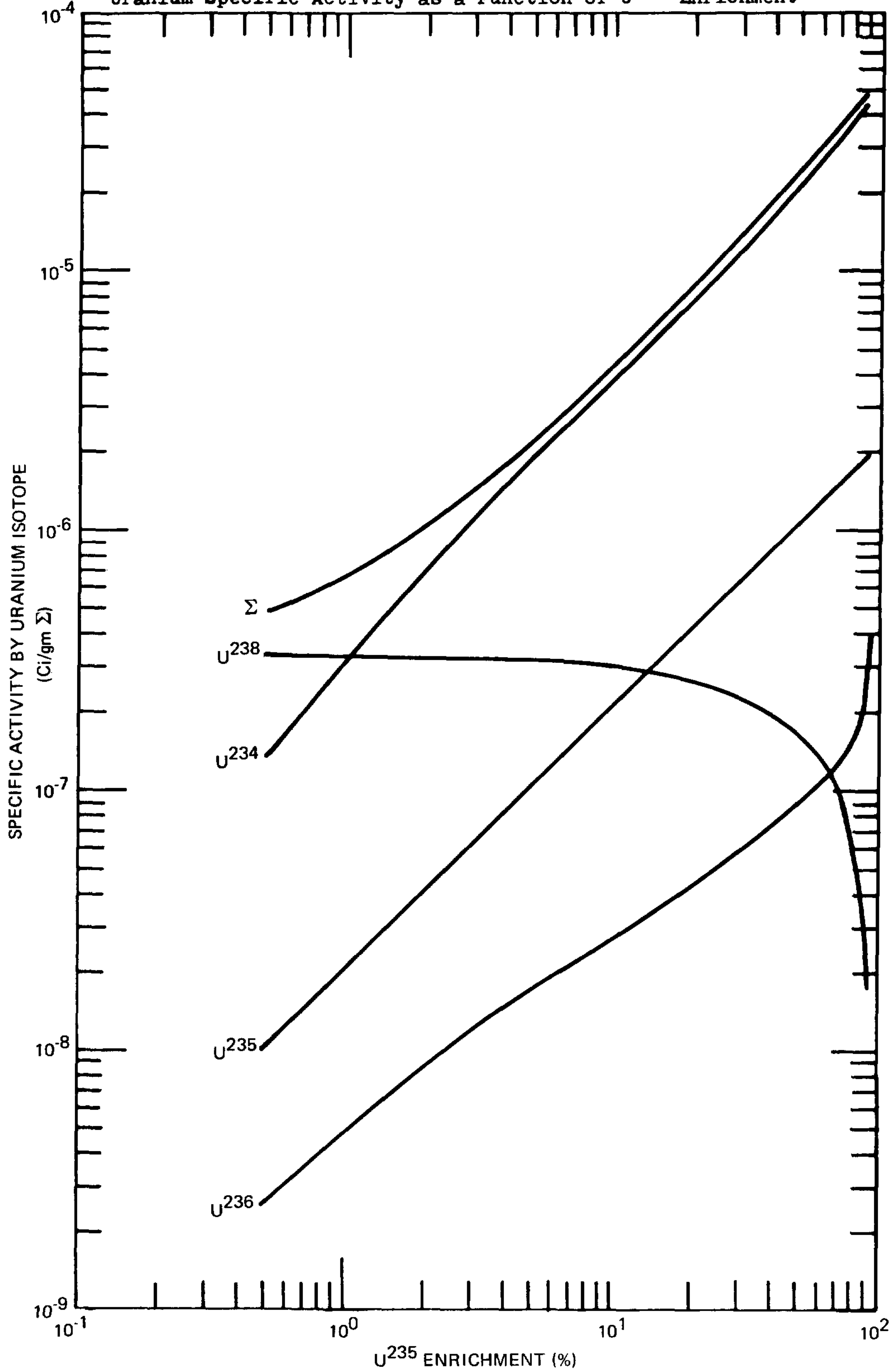
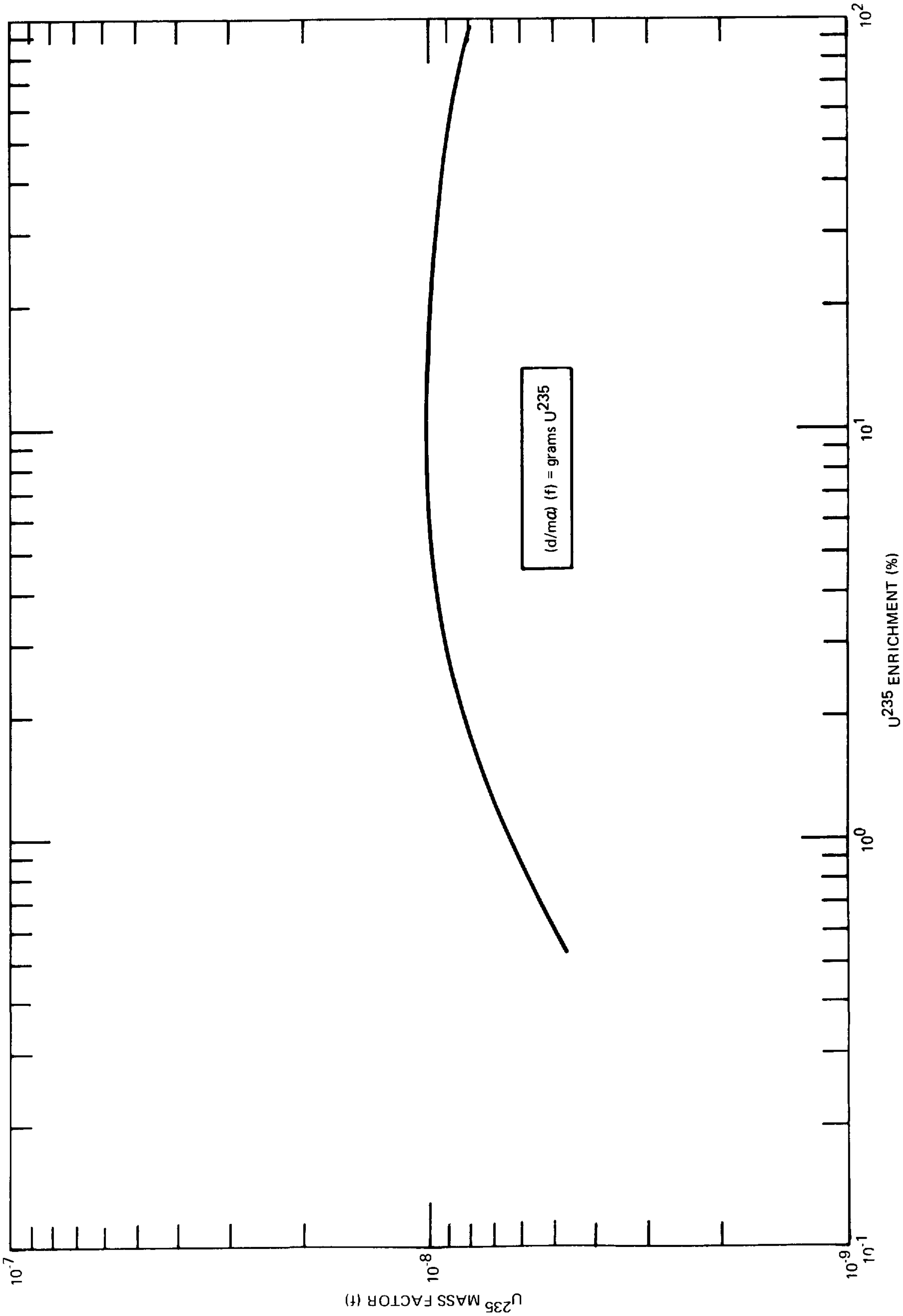


Figure 2

Factors for Determining U^{235} Mass from Alpha Activity



S.C.E.N.I.C. SOUTHERN CALIFORNIA EDISON NUCLEAR INVENTORY CONTROL

By B. D. Sinclair, S. F. Deng,
H. J. Fenech, P. K. Shen
Southern California Edison
Rosemead, Calif.

Nomenclature

$B_{o,b}$ — input initial burnup (MWD / MTM) for fuel batch b

B^k_{rel} — relative axial burnup for axial region k

$C_{u,b}$ — density correction factor for fuel batch b

$e^c_{i,j,k}$ — local energy (MWH) produced by axial region k of fuel assembly j accumulated up to time step i for cycle c

E^c_i — cycle energy (10^3MWH) at time step i of cycle c (E^c_1 equals 0 for each cycle)

FB(j) — fuel batch index for fuel assembly j

FE(b) — enrichment index corresponding to each fuel batch b

$F_{nor,b}$ — batchwise energy normalization factor

$FR_{nor,j}$ — rate modification factor
— Power density at radial location j in future cycle
power density at the same radial location j in current cycle

$M_{f,b}$ — input mass (MTM) of fuel metal in batch b

$M_{j,k,n}$ — isotopic mass for isotope n at axial region k of fuel assembly j

$N_{b,co}$ — number of batches in core

$N_{f,b}$ — number of fuel assemblies in fuel batch b

$N_{f,co}$ — number of fuel assemblies in core

n_k — number of axial regions per fuel assembly

n^c_f — total number of integration time steps in cycle c

$R^c_{i,j,k}$ — local energy rate (MWH / 10^3MWH) at time step i of cycle c for axial region k of fuel assembly j

$RS^c_{j,k}$ — the sum of the local energy rates for assembly j of all time steps in cycle c

v_k — input volume fraction of fuel axial region k (fuel volume of axial region k / V_f

V_f — volume (cm^3) of fuel in one fuel assembly

$\rho_{m,n,\ell}$ — input density (gm / cm^3) table entry m for isotope n and enrichment index ℓ

ρ_n — local density (gm / cm^3) for isotope n

A computer code SCENIC(1) was developed at Southern California Edison Company to permit in-house fuel management and isotopic inventory control for a pressurized water reactor.

General Description

SCENIC can calculate and predict the assemblywise and batchwise burn-up distributions and isotopic inventories for the current and future fuel cycles from the input values of total cycle energy and the local assembly axial power fractions.

The local axial power fractions are computed by the INCORE(2) code — an experimental data processing code. In INCORE, the measured neutron flux data (by Aeroball thimbles located in the reactor core) is used in conjunction with the analytic power to flux ratios (calculated by a two-dimensional, few group diffusion calculation using PDQ-7(3)) to obtain the local axial power fractions.

SCENIC mathematically treats the local power fractions as energy production rate data, integrating them with respect to the total cycle energy to obtain the local energy production distribution at four axial segments. The local energy production distribution is then summed axially to obtain the fuel assembly and fuel batch energy production distribution. The energy production distributions are used in the code to calculate the respective fuel burnup distributions.

The isotopic inventories are computed by interpolation within tables of isotopic density versus fuel burnup. The tables are generated by an in-house cell depletion and energy spectrum generation code — NUMICE[4] (modified LEOPARD[5] code) which calculates the isotopic densities as functions of burnup within a homogenized fuel pin cell which represents the average fuel pin within a fuel assembly. The interpolated local isotopic densities are multiplied by the fuel volume to obtain the local mass for each isotope. These masses are then summed axially to obtain the isotopic inventories by fuel assembly and by fuel batch.

In the end of life predictions for the current fuel cycle where the Aeroball data is not available, the local power fractions for each axial region of each fuel assembly at all the previous time steps are averaged by the code. These averages are assumed to be accurate representations of the local power fractions at the end of life. Then the end of life energy production distribution is determined analogously to the determination of the accumulated energy production distribution at each time step for which Aeroball data is available.

Future cycle prediction is planned by assuming an equilibrium core. Thus, the local power fractions for a current fuel cycle are assumed to be valid for predicting the next fuel cycle. The code includes power fraction normalization factors as input so that power shifting which occurs during plant operation is linearly accounted for in the algorithm.

FORMULATION

Initialization and Normalization

At the beginning of each fuel cycle, the initial energy produced by each fuel assembly is required, these initial energies are input to the code. They are zero if the assembly contains fresh fuel, or the same as the end of life values from the previous cycle, or any other known values.

After the initial energy of all the fuel assemblies has been initialized, the batchwise energies can be optionally normalized to an input quantity. At the beginning of each fuel cycle, this input quantity comes from the design calculations. The code first computes the normalization factors,

$$F_{nor,b} = \frac{(24)(M_{f,b})(B_{o,b})}{\sum\limits_{\substack{j \\ FB(j)=b}} \sum\limits_{k} e_{1,j,k}]} \quad \text{if } B_{o,b} > 0 \qquad b=1,\ldots,N_{b,co}$$

$$= 1 \quad \text{if } B_{o,b} = 0 \tag{1}$$

these factors are then multiplied by the assemblies' initial energies to obtain the final initialization.

Integration

On all time steps, except the first, SCENIC applies the trapezoidal rule to integrate the input local energy rate data (local power fractions) come from INCORE,

$$e^{c}_{i,j,k} = e^{c}_{i-1,k} + (1/2)(R^{c}_{i,j,k}+R^{c}_{i-1,j,k})(E^{c}_{i} - E^{c}_{i-1}) \qquad k=1,\ldots,n_k \quad j=1,\ldots,n_{f,co} \tag{2}$$

Since the trapezoidal rule is used for integration, it is assumed that the local energy production can be closely approximated by a second order polynomial.

As indicated above, the first time step may be an exception to the general rule of applying trapezoidal integration. This exception occurs only when energy rate data is not available at the beginning of the cycle. In such cases the initialization is performed and then linear integration is used from E_1c — 0 to $E_2{}^c$ where $E_2{}^c$ is the cycle energy at which the first set of energy rate data is available. The linear integration takes the form

$$e^{c}_{2,j,k} = e^{c}_{1,j,k} + (R^{c}_{2}) \cdot (E^{c}_{2}) \qquad k=1,\ldots,n_k \quad j=1,\ldots,N_{f,co} \tag{3}$$

Since any numerical integration results in minor inaccuracies, the code performs a normalization procedure following each integration step. The local energies are then normalized to a known total energy output by a computed normalization factor.

Prediction of Burnup For a Future Cycle

As stated earlier, the prediction in the burnup for future cycle is based on an equilibrium core. In other words, the local energy rate data for cycle c is assumed to be valid for cycle (c + 1). For a non-equilibrium core a rate modification factor is introduced to aid in predicting cycle (c + 1) from cycle c energy rate data. By assuming linearity and using for the rate modification factors the ratio of the power density at radial location j in cycle c + 1 to the power density at location j in cycle c, the equilibrium core assumption is replaced with a linearity assumption. The power densities at each radial location are readily available from design calculations (theoretical results) prepared at the beginning of each fuel cycle.

SCENIC associates optionally an input rate modification factor with each fuel assembly. During the integration, the local axial region energy rates are multiplied by the corresponding factor so that,

$$e^{c_2}_{i,j,k} = e^{c_2}_{i-1,j,k} + (F^{R}_{nor,j}) \cdot (1/2) \cdot (R^{c_1}_{i,j,k} + R^{c_1}_{i-1,j,k}) \cdot (E^{c_1}_{i} - E^{c_1}_{i-1}) \tag{4}$$

$$e^{c_2}_{2,j,k} = e^{c_2}_{1,j,k} + (F^R_{nor,j})\cdot(R_2^{c_1})\cdot(E_2^{c_1}) \quad k=1,\ldots,n_k \quad j=1,\ldots,N_{f,co} \tag{5}$$

where $F_{nor,j}{}^R$ is the rate modification factor input for the fuel assembly at radial location j, c_2 the fuel cycle being predicted, and c_1 the fuel cycle for which rate data is available.

Interpolation or Extrapolation Within a Cycle

SCENIC has the capability to use the history of energy production it has generated and to interpolate or extrapolate to a desired value of cycle energy within the cycle currently being processed. The value of cycle energy is supplied as input and the program determines whether it is an interpolation within the history it has developed up to that time step or an extrapolation to a future time step.

Interpolation employs the Lagrange method[6] applied to the history of energy production. The resulting equation is

$$e^c_{e,k,1} = \sum_{i=MIN}^{MAX} \frac{\prod_{\substack{\ell=MIN \\ \ell\neq e}}^{MAX} (E^c_e - E^c_\ell)}{\prod_{\substack{\ell=MIN \\ \ell=i}}^{MAX} (E^c_i - E^c_\ell)} e^c_{i,j,k} \quad k=1,\ldots,n_k \quad j=1,\ldots,N_{f,co} \tag{6}$$

where $E_e{}^c$ is the input value of cycle energy for the interpolation and MAX and MIN are the limits of the polynomial degree.

Extrapolation is performed by a linear integration using the average energy rate at each local, axial fuel region,

$$e^c_{e,j,k} = e^c_{I,j,k} + (RS^c_{j,k}/n^c_t) \cdot (E^c_e - E^c_I) \tag{7}$$

where I designates the last integration time step.

Computation of Fuel Burnups

The burnups are calculated by making the appropriate sums of energy and then converting the units from megawatts hours (MWH) to megawatt-days per metric ton of initial fuel metal (MWD/MTM). The equations are:

local burnup =

$$(e_{i,j,k})\cdot(N_{f,b})/[(24)\cdot(M_{f,b})\cdot(v_k)] \tag{8}$$

fuel assembly burnup =

$$(\sum_k e_{i,j,k})\cdot(N_{f,b})/[(24)\cdot(M_{f,b})] \tag{9}$$

fuel batch burnup =

$$(\sum_{\substack{j \\ FB(j)=b}} \sum_k e_{i,j,k})/[(24)\cdot(M_{f,b})] \tag{10}$$

total core burnup =

$$(\sum_j \sum_k e_{i,j,k})/[(24)\cdot(\sum_b M_{f,b})] \quad . \tag{11}$$

It should be noted that the first two equations assume that the mass of fuel in a batch is evenly distributed to the assemblies comprising that batch.

SCENIC can also optionally print the relative axial burnups. If the option is in effect, these values are printed for each fuel assembly with non-zero burnup. The values indicate the axial distribution of burnup and are computed as

$$B^k_{rel} = e_{i,j,k}/[(\sum e_{i,j,k})\cdot(v_k)] \tag{12}$$

Isotopic Mass Inventories

The first step in the calculation of the isotopic masses is to compute the local density of each isotope from the local burnup. SCENIC employs Newton's divided difference interpolation[6] in the input tables of isotopic density (generated from NUMICE code). The divided difference tables are computed once when the isotopic density tables are read and then used for the interpolations.

After calculating the local density ρ_n(gm/cm^3) for isotope n by interpolation, SCENIC computes the local isotopic mass (gm) by

$$M_{j,k,n} = (C_{u,b})\cdot(\rho_n)\cdot(V_f)\cdot(v_k) \tag{13}$$

where $C_{u,b}$ is a density table correction factor computed by SCENIC at the beginning of the fuel cycle for each fuel batch b by the following equation,

$$C_{u,b} = (10^6)\cdot(M_{f,b})/[(V_f)\cdot(N_{f,b}) \cdot \sum_n \rho_{1,n,FE(b)})] \tag{14}$$

where $\rho_{1,n,\ell}$ is the input density for isotope n of the table ℓ (at zero burnup since it is the first entry). Thus, $C_{u,b}$ corrects for differences between the measured density of the fuel and the theoretical density for the fuel. To preserve accuracy, the axial local compositions for each fuel assembly are calculated from each axial local burnup and then summed to obtain the total fuel element composition. SCENIC also obtains sums for each fuel batch and for the entire core.

Outputs by SCENIC

(1) Isotopic Density Tables

Isotopic densities (gm/cm^3) versus burnup (MWD/MTM) are printed out in these tables according to different enrichments. The present version of SCENIC contains the following isotopes: U^{235}, U^{236}, U^{238}, Pu^{239}, Pu^{240}, Pu^{241}, Pu^{242}, Np^{237}.

(2) Reload Tables

For each fuel cycle, SCENIC prints a reload summary by fuel assembly and by fuel batch. In the summary by fuel assembly, the new and old location in the core of the assembly, the batch where the assembly is in, the enrichment, fuel mass, burnup and energy of the assembly are all printed out. In the summary by batch, the enrichment, fuel mass, number of assemblies, density normalization factor of that batch and the total core loading are printed out. Following the reload summary by batch, the optional initial fuel batch burnups and the rate modification factors are also printed out.

(3) Core Composition Tables

The isotopic inventory data are in these tables. In the core composition table by assembly, the accumulated assemblywise burnup, energy, isotopic masses, total U, total Pu, U + Pu, Pu^{239} + Pu^{241}, U^{235} / U, (Pu^{239} + Pu^{241}) / Pu and Pu / (U + Pu) are all printed out.

(4) In addition to the above listed information, the top 40 burnups by assembly and by axial region, the optional history tape listing (local energy produced in each axial region of a fuel assembly at each time step) and a print plot (fuel batch burnup versus cycle burnup) are output by SCENIC.

A typical output by batch for Cycle 1 of San Onofre Nuclear Generating Station Unit No. 1 is given on Figure 1, and the corresponding loading is shown on Figure 2.

SUMMARY

The development of the fuel management program SCENIC by Southern California Edison Company has achieved the following:

(1) It has proved to be a useful exercise in the development of Nuclear Analysis methods presently underway.

(2) It has provided Southern California Edison Company with an invaluable tool to process the in-core data into present and projected fuel inventory in an operating core.

(3) The outputs from SCENIC have been checked with reactor Vendor's computed values and are sufficiently reliable to be used by our Fuel Supply Department. These data are presently needed by this Department to upgrade the plant nuclear fuel inventory and prepare the regulatory AEC reports quarterly.

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SONGS I SCE-001-EOL PREDICT 15304 MWD/MTM 1 *** SCENIC *** 01/27/72 13:32:57 PAGE 43
CYCLE NUMBER 1

CORE COMPOSITION BY BATCH

BATCH	ENRICH	BURNUP (MWD/MTM)	ENERGY (MWD)	U--235 (KG)	U--236 (KG)	U--238 (KG)	PU-239 (KG)	PU-240 (KG)	PU-241 (GM)	PU-242 (GM)	NP-237 (GM)
1	1	18079.3	350828.9	324.8504	49.3756	18512.9838	106.5315	24.9305	15671.6071	2527.8157	3836.9537
2	2	16966.7	323793.3	373.3895	48.1717	18181.0050	104.2842	21.8268	13763.5032	1935.1065	3513.7700
3	3	10753.9	202281.7	530.4908	35.1243	17932.2095	82.7430	11.3548	6144.6348	509.7329	1885.0983
CORE	*	15304.0	876903.9	1228.7306	132.6716	54626.1983	293.5588	58.1120	35579.7450	4972.6551	9235.8220

BATCH	TOTAL U (MT)	TOTAL PU (MT)	U+PU (MT)	PU239+PU241 (MT)	(U235)/U (W/O)	(PU239+PU241)/PU (W/O)	PU/(U+PU) (W/O)
1	18.88721	0.14966	19.03687	0.12220	1.71995	81.65306	0.78617
2	18.60257	0.14181	18.74438	0.11805	2.00719	83.24382	0.75654
3	18.49782	0.10075	18.59858	0.08889	2.86785	88.22409	0.54172
CORE	55.98760	0.39222	56.37982	0.32914	2.19465	83.91613	0.69568

FIGURE 1

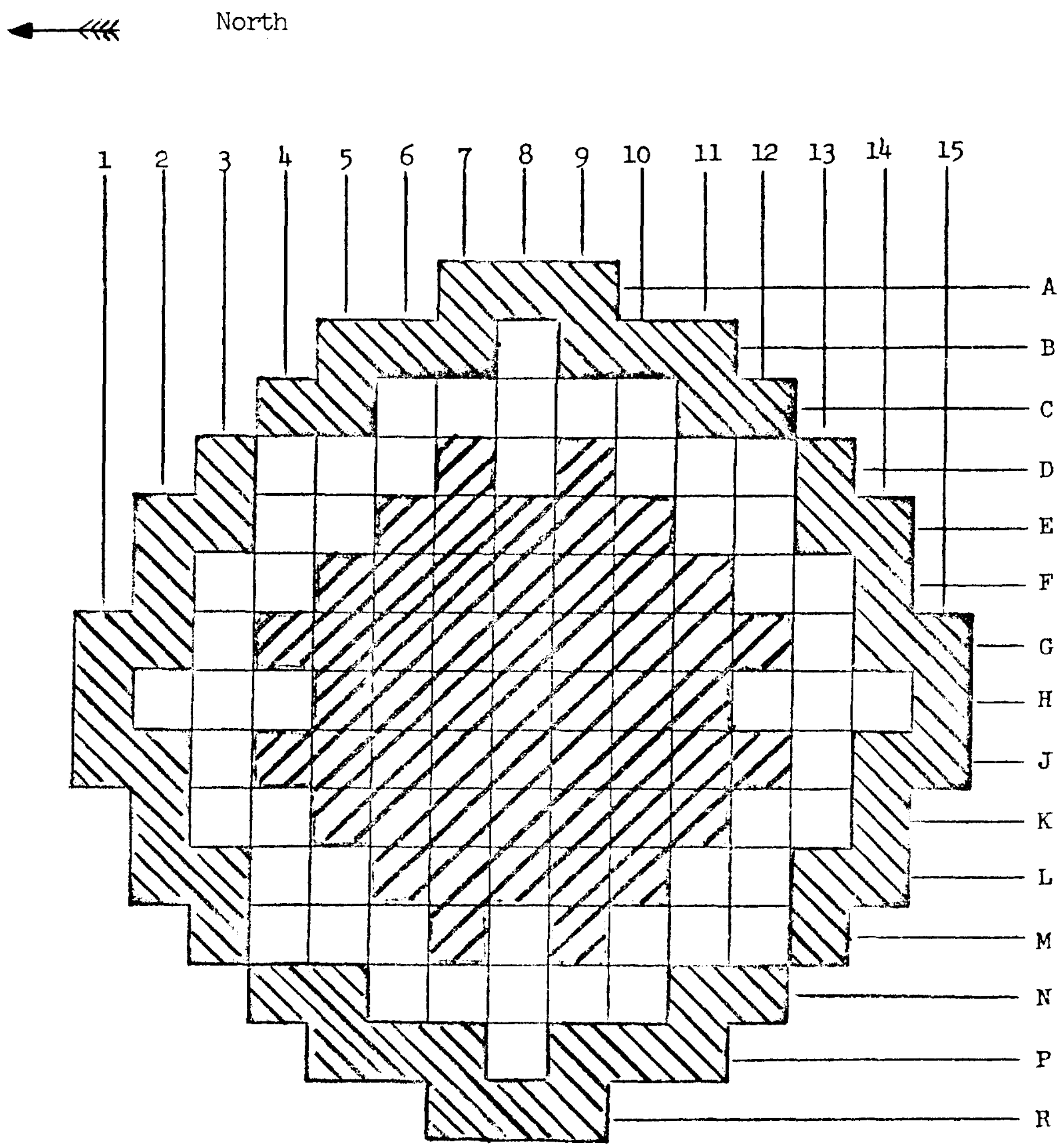

Figure 2 Initial Fuel Loading for San Onofre Nuclear Generating Station, Unit 1

Batch 1 - 3.15 W/O (53 assemblies)

Batch 2 - 3.40 W/O (52 assemblies)

Batch 3 - 3.85 W/O (52 assemblies)

SAFEGUARDS AT KANSAS STATE UNIVERSITY: PART II

By F. A. COSTANZI and R. B. LEACHMAN

CONTROL PREFERENCE SURVEYS

D. W. Brady and D. A. Zollman

National

The objective of this research[6, 7, 8] was to ascertain the extent of the differences between the regulator (AEC) and the regulated (industry) and the nature of the variables which elicit responses concerning regulation. To collect the data necessary to this purpose, personal interviews were conducted. The interviewees were 85 key people in government and industry who were in either policy determining or policy influencing roles in relation to safeguards in the United States.

Hypothetical safeguards control plans (systems) reflecting differing degrees of external control were presented to interviewees for their selection and comments. These control plans ranged from system I, which provided for the least stringent set of controls, to system V, which provided for the most stringent set of controls. Each of the five control plans (systems) contained the same component parts, presented with progressively greater stringency from I to V.

That the industrial interviewees should prefer a safeguards control plan which is less stringent than that preferred by the AEC interviewees is logical. Moreover, it was found that the AEC interviewees and the industrial interviewee not only prefer different systems, but also perceive the present system differently.

The responses of the interviewees were examined in terms of the component parts of the control plans in a manner that isolates and analyzes the underlying patterns in these responses. The interviewees were categorized into three groups: AEC personnel, those in the nuclear industry working with reactors, and industrialists working in the area of reprocessing and fabrication. The nuclear industry was separated into reactor and reprocessing-fabrication categories because of the differing nature of the technology involved.

The greatest disparities between industry and AEC regarding safeguards occurred in the areas of AEC reaction to reports, the funding of safeguards and where measurements are to be taken. The disagreements are less severe but nonetheless statistically significant in the areas of controlling plant design, what types of measures to take, the denial of access, reporting diversion, AEC reaction to written reports, IAEA relationship to AEC safeguards and the number of inventories. The reactor interviewees and the reprocessing-fabrication interviewees were found to be in disagreement with each other over safeguards funding, where measurements are to be taken, reporting diversions, and records.

For the industry as a whole, the variables each interviewee most closely identified with his choice of system (control plan) dealt with the physical presence of the AEC in the facilities, which presumably reflects concern by industrial interviewees that the presence of AEC personnel in the facility might disrupt orderly business procedure. Of secondary concern to industrial interviewees were questions concerning AEC's power to regulate. Least related to systems choice is the group of variables which we termed accountability factor, e.g. records keeping.

For the AEC interviewees, the group of questions relating to their system (control plan) choice all relate to the AEC's power to regulate. The second factor related to the system choice of the AEC interviewees reflects a general concern for safeguarding materials during transportation. The third factor reflects a concern for measurements. The individuals interviewed who work for Regulatory almost unanimously responded with the same pattern on the questions concerning measurements.

Disagreement between the reactor interviewees and the reprocessing-fabrication interviewees was attributed to the two samples identifying control plans (systems) with different components. The most important components for the reactor interviewees involved record keeping while for the reprocessing-fabrication interviewees the most important components related to Intrusiveness. This finding is in keeping with the argument that technological differences between these two components of the nuclear industry affect both general preferences regarding stringency and which aspects of the control plan particularly influence the choice of plan.

In this work the study of implementing nuclear safeguards was characterized as a study of regulatory politics. Reprocessing and fabrication interviewees were most opposed to strong regulatory practices, reactor personnel were less so, and the AEC sample preferred the strongest regulatory practices. Despite substantial disagreements, there was agreement upon some component parts of the hypothetical systems, e.g., transportation. The differences of opinion relate to differing perceptions of the safeguards problem: specifically, the nuclear industry's concern with safeguards interfering with its right to "run a business," and the AEC's concern with its right to regulate.

International

To investigate the interaction of the political and technical aspects of IAEA safeguards, 84 safeguards experts of 23 different nationalities as well as safeguards experts in

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relevant international organizations were personally interviewed.[9, 10, 11] The interviewees include nuclear experts ranging from nations with no plans to generate electrical energy by nuclear means to those with large-scale nuclear energy programs. Hypothetical IAEA control plans were presented for the interviewee's selection and comment. The control plans ranged from the least stringent, system I, to the most stringent, system V.

An important aspect of the technological interaction in the international safeguards plan is reflected by the notion that the experience of a nation in the generation of nuclear energy will influence its nuclear experts' perception of a safeguards with regard to how much external control they would prefer the IAEA to exercise, and the amount of external control they feel the IAEA's safeguards plan will ultimately have. The following figure shows the preferred hypothetical system averaged over all individuals in the nation of nations who have signed the NPT plotted against the time since the first electricity generating nuclear reactor was placed into operation in that nation. The trend is quite clear: the longer a nation has been generating electricity by nuclear energy the more stringent external control the nuclear experts of that State prefer. A similar result in terms of nuclear capacity is seen in the experts' perception of the final IAEA system. The experts of the nation with the greatest generating capacity (the United States) expect a control plan (system) considerably more stringent than other nations with nuclear power stations. Further, the nations with no present nuclear capacity expect much less stringency than either of the other groups. Interestingly, the same pattern is reflected by those interviewed in the IAEA Department of Safeguards and Inspection. Every interviewee on the Agency staff identified his preference of hypothetical system with his view of the terms of the Non-Proliferation Treaty, hence, the same relation holds for the staff members' perception of the actual safeguards system to be established under the Non-Proliferation Treaty.

The components of IAEA control plan for which disagreement exists between at least two of the three groups (nations with reactors, nations with developing reactor programs, nations with no plans for developing reactor programs) are:

1) To what extent would the IAEA be involved in the process of designing the safeguard procedures of the nuclear facility,
2) Where should independent measurements be performed by IAEA,
3) What type of independent measurements should be made by the IAEA,
4) What denial of access due to the loss of proprietory information should be allowed,
5) How suspected diversions are reported to IAEA, and
6) How disputes between nations and IAEA are settled.

For each component, the nuclear experts from the United States chose, on the average, the most stringent response of the three groups. The lowest mean response was, however, distributed between the other two groups.

An investigation into what components were perceived as relevant, revealed that members of the United States identified components related to the control of nuclear material as most important (key group).

For nuclear generating countries other than the U.S., the group of components most closely related to the choice of a hypothetical system (control plan), contains three of the United States' key group components (type and place of measurements and design control). The four U.S. components which do not appear in the key group for other generating countries require intrusions into the plant (inventories, reporting and reviewing records, reaction to a loss and changing plant design). The most important components for other generating countries were reporting suspected diversions **to** IAEA, denying access to IAEA for **their own** safeguards operations. This group of components are elements of a **verification** plan rather than a **control** plan.

The identification of components for the interviewees from nations with no nuclear power capability is much less clear. However, the components most closely related to the choice of a hypothetical IAEA plan contain elements which require some intrusion into the facility (measurements and changing plant practices).

This study indicates the direction safeguards may take in the future. As nuclear experience increases, nations may prefer more stringent safeguards systems. However, other nations will be just beginning a nuclear program, and disagreements concerning the implementation of the safeguards might be expected. On the other hand, those interviewed here have agreed on many of the components of the safeguards plan, which can be expected to cause little friction during the coming years with safeguards applied under the NPT.

INSPECTOR-DIVERTER GAME THEORY

F. A. Costanzi

Zero-sum Games

The objective of mathematical game theory as applied to nuclear materials safeguards is to provide an inspectorate with "optimal" strategies for inspection which would allow effective safeguards at minimal cost. Unfortunately, this objective is far from being achieved.

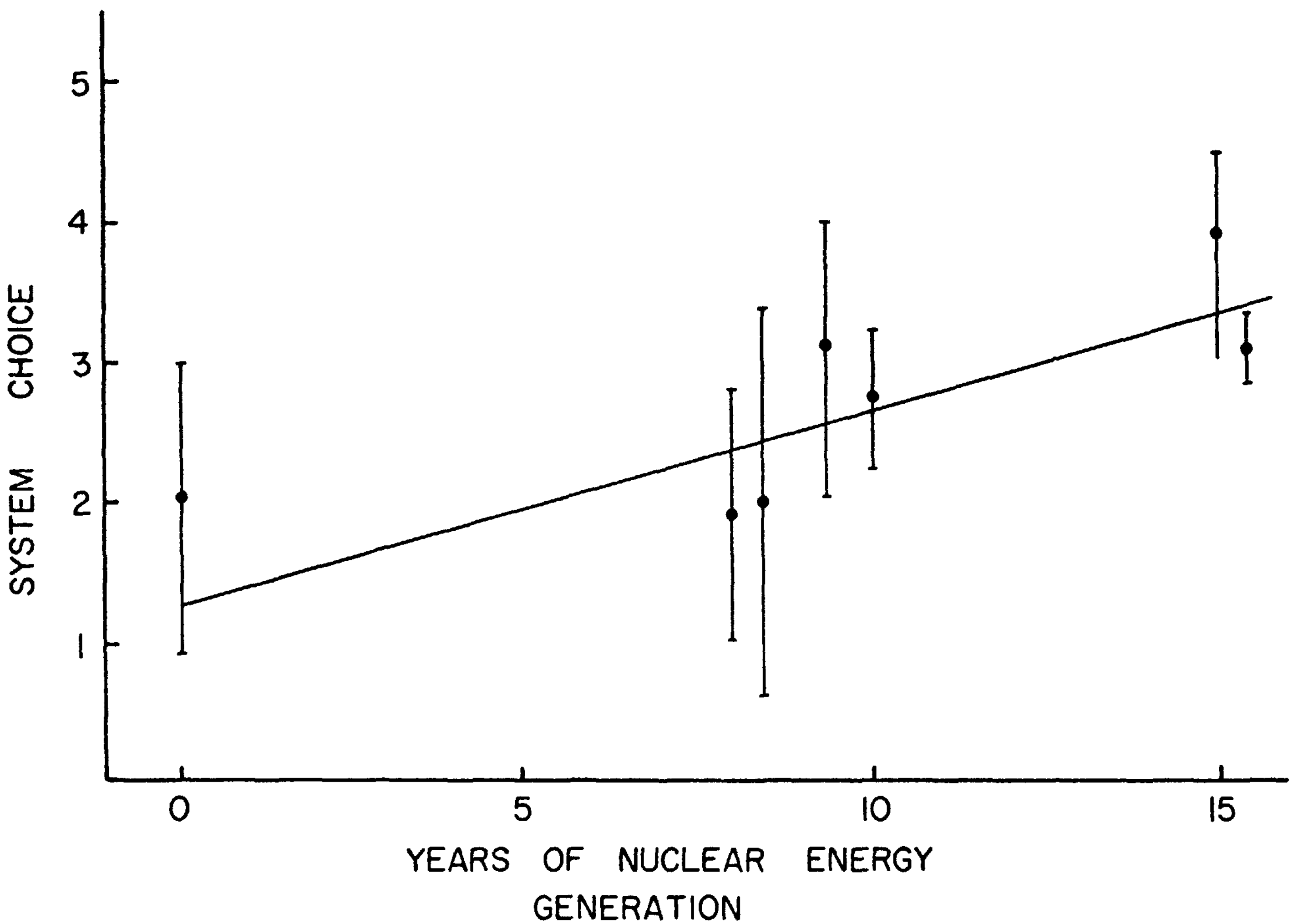
Existing safeguards models to which game theory has been applied are all of the deterrence variety. The presumption is that if the potential diverter expects to lose rather than gain by diversion he will be deterred and not divert. However, our study has made it clear that this deterrent condition can be obtained for these models without use of game theory. In fact, our study shows that only a negotiated solution of the nonzero-sum game requires the use of game theory. We illustrate this point by examining an existing safeguards model which typifies game-theoretic applications to safeguards.

The model is provided by Avenhaus and Gupta[5] in which they consider only spatial aspects of a problem, which in their case was the inspecting of facilities in a fuel cycle. They assume M areas safeguarded by the inspectorate. Safeguards is effected by dispatching inspectors to $J<M$ of the areas. The diverter, in order to accumulate the hazard amount of material, must divert from $r<M$ areas. The diversion is detected if one or more of the r areas in which the diverter is operating is inspected by the J inspectors. The probability of such an occurrence, i.e., one of more inspectors inspecting one or more of the r areas, is given by $P(J,r,M)$. The expectation of success of the diverter is the probability that none of the areas will be inspected, and is therefore, $1-P(J,r,M)$. The diverter attaches a value d to a successful diversion and a loss -c to a detected diversion.

By use of probability theory, the expectation value realized by the diverter for diversion can be calculated:

$$V = (1-P(J,r,M))d-P(J,r,M)c \quad . \qquad (1)$$

It is further defined that the expectation value for legal behavior (no diversion) is zero. If V is negative, i.e., the potential diverter expects to lose rather than gain by at-


SYSTEM CHOICE
5
4
3
2
1
0
5
10
15
YEARS OF NUCLEAR ENERGY GENERATION

tempting diversion, he will act "rationally' and not divert. This is termed the deterrent condition and from equation (1) is seen to be:

$$P(J,r,M) > \frac{d}{d+c} \qquad (2)$$

On the other hand, Avenhaus and Gupta obtained the same condition (2) by constructing a zero-sum game. The diverter has two possible strategies: to not divert, (denoted by strategy $\bar{D}$ for which he recieves payoff zero; or to divert (denoted by D) for which he receives d if the inspectorate does not inspect (denoted by $\bar{I}$) any of the r areas from which the diversion takes place or a loss -c if one or more of the r areas is inspected (denoted by I). The game is:

INSPECTOR

	I	$\bar{I}$
D	−c	d
$\bar{D}$	0	0

Under assumptions of this model, the inspectorate is not inspecting everywhere, but rather must distribute its efforts over the M areas with J< M inspectors. Although Avenhaus and Gupta term this a minimax strategy, the inspectorate actually plays a mixed strategy of $I:\bar{I} = P:(1-P)$, where $P = P(J,r,M)$. The value of the game to the diverter is:

$$D: \quad -cP + d(1-P) = V \qquad (3a)$$

$$\bar{D}: \quad \bar{V} = 0 \;. \qquad (3b)$$

Clearly, it is to the diverter's interest to play $\bar{D}$, i.e. not to divert if $V < 0 = \bar{V}$. But this is just a repeat of equations (1) and (2) obtained from probability theory. The effects of this model, whether analyzed by straight-forward probability theory or by constructing a game, are thereby the same: the diverter can be deterred if and only if his expected value for the diversion is negative. The manner in which the inspector distributes his efforts over the M areas is **independent** of the payoffs. Although both probability theory and game theory yield equation (2), neither can provide any method of obtaining the probability of detection necessary to satisfy equation (2).

Nonzero-Sum Games

It has often been suggested that the proper approach to safeguards is instead via nonzero-sum games. In our study we have utilized nonzero-sum games by involving both penalties and separate payoffs to the inspector and diverter.

Even with the introduction of a penalty to the inspectorate for falsely alleging a diversion in a nonzero-sum game, inspection strategies are still independent of diverter payoffs. However, in the nonzero-sum game, the inspection option is linked with the false allegation (error of the first kind) penalty to the inspector for a detected diversion, payoff -e for an undetected diversion, and payoff -b for a false allegation. Payoffs to the potential diverter are d for a successful diversion, -c for a detected diversion, and -g for a false allegation. It is assumed that the degree of certainty of detection by an individual inspection is $(1-P_f)$ where P_f was the probability of an error in inspection judgment. The payoff matrix to the inspector is:

INSPECTOR

		I	$\bar{I}$
	D	$a(1-P_f)-eP_f$	−e
DIVERTER	$\bar{D}$	$-bP_f$	0

The diverter's payoff matrix is:

INSPECTOR

		I	$\bar{I}$
	D	$dP_f-c(1-P_f)$	d
DIVERTER	$\bar{D}$	$-gP_f$	0

The probability of a judgmental error on the part of the inspector is assumed to be sufficiently small such that $a(1-P_f)-eP_f > 0$, and $dP_f-c(1-P_f) < 0$. By labeling these two quantities a′ and -c′, respectively, the payoff matrix becomes:

INSPECTOR

	I	$\bar{I}$
D	−c′, a′	d, −e
$\bar{D}$	−g′, −b′	0, 0,

where $g' = gP_f$, $b' = bP_f$, and the entries (s,t) are payoffs, s to the diverter, and t to the inspector.

Nonzero-sum games can be used to derive conditions under which inspector-diverter collusion is not advantageous for either. Specifically, the solution to this game gives conditions on the parameters a′, b′, c′, d, e, g′ such that collusion between inspector and the diverter is **not** profitable to the inspector and the potential diverter is deterred. Although such a solution provides the "optimal" value of P by algebraic relations between a′, b′, c′, d, e, g′, the basic difficulty remains of assigning quantities to the actions represented by these terms.

As before, deterrence requires that the expectation value to the diverter be less for playing the diversion strategy than for playing the legal (no diversion) strategy. The condition necessary for deterrence in terms of payoff to **both** inspector and diverter is found to be:

$$\frac{e}{a'+b'+e} > \frac{d}{c'+d-g'} \;, \quad P = \frac{e}{a'+b'+e} \qquad (3)$$

Note that P, the probability of detecting a diversion, is not necessarily the highest attainable, but rather the value for which the inspector suffers minimum loss regardless of diverter's actions. Equation (3) is a statement on the rewards and penalties imposed upon the inspector relative to the diverter sufficient for deterrence.

If the payoffs a′, b′, c′, d, e, g′ are such that relation (3) is not satisfied, the negotiated solution (collusion) can be found through nonzero-sum game theory. The negotiated solution (Nash) to the game is:

$$X = (E^* + b'P)/[(a'+b'+e)P-e] \;, \qquad (4)$$

where E^* is the expected value to the inspector and X is the optimal probability for the diverter to divert when the inspector uses a detection probability P. Note that $E^* > -b'P$, the minimum value to the inspector, implies that X must be greater than zero. That is, if the inspector wishes to receive more than the minimum he must agree to some degree of (successful) diversion. This agreement to diversion by the inspector is the rational outcome of the conditions assumed: payoffs a', b', c', d, e, g' are such that collusion is not "rationally" preventable.

Summary

For the models examined, in every case the inspection strategies were not provided by the model. If strategies are to be found, the model must itself be sufficiently complex to give differing values of payoff to the diverter for diversion from the various times-areas involved. The diverter must regard successful diversion from one area as more desirable than from another. We have observed that the use of game theory in such a situation would render greater information than the use of probability theory, viz., how the inspector's efforts are to be distributed. However, if there are M areas-times from which a diversion can take place, the inspector must know the values of a successful diversion from each of the areas-times to the diverter as well as the penalty to the diverter for unsuccessful diversions in each of the areas. Thus the two-parameter game has been expanded to a 2M parameter game, soluable provided one know the value of each of the 2M parameters.

Deterrence

It is the opinion of the author that the use of any model to advise what inspection effort is necessary for deterrence is at best speculative, and perhaps dangerous, simply because of the difficulty in quantifying the payoff parameters. Speculative, because one has no method of verifying that the payoff entries used by the inspector are indeed the same as perceived by the potential diverter. Dangerous, because any deterrence approach presupposes that the diverter will not divert, i.e. be deterred, if his expectation value is negative. This is the assumption of rationality generic to all game-theoretic analyses. Take, for example the condition for deterrence, equation (2),

$$P > \frac{d}{d+c} \quad . \tag{2}$$

If we assume d equals c, then by equation (2) the diverter will be deterred ($V < 0$) if the probability of detection is > 50 percent. Take P equals 51 percent, then by this model, be it analyzed by game theory or probability theory, the "rational" diverter will not divert ($V < 0$). However, the irrational diverter, or simply one who perceives $d > c$ will not be deterred, will divert, with only 51 percent probability of being caught by the inspectorate — a 49 percent probability of the theft being detected by detonation of a nuclear device.

Admittedly, we have illustrated a rather extreme example, however the reality of the danger of deterrence remains. Obviously 100 percent probability of detection is not attainable, however, it appears that the only reasonable model is one not based on deterrence, but rather one based on maximizing the probability of detection with whatever funds are available. The minimum value of the probability P acceptable is not to be given by models; it is a social-political question, not a mathematical one. The purpose of safeguards models should be to attain the acceptable P at minimum cost.

Optimization of Inspections

F. A. Costanzi, F. A. Tillman, and S. Chatterjee

Inspection Deployment for Optimized Detection

Our purpose is to use computational methods for the allocation of inspection resources to optimize the effectiveness of detection of diversions.

The nuclear fuel industry first illustrated by Avenhaus and Gupta[5] formed the basis for these reliability optimization studies. Safeguards was protrayed as a reliability problem with system reliability defined as the overall, or system, probability of detecting diversion. Proper consideration was taken of both the number of measurements that need to be falsified at each of the accessible points to accumulate the hazardous quantity, and the probability of detecting the successive falsifications through the number of inspector measurements made at random at each point within the cost budget of the inspectors. The problem was then to maximize a system probability of detection subject to an inspection cost constraint.

To solve this problem the Sequential Unconstrained Minimization Technique (SUMT)[12] was employed. The transformation of a constrained minimization problem into a sequence of unconstrained minimization problems is the underlying principle of SUMT.

The results for this model are displayed in the following figure. Relatively high levels of system reliabilities were obtained for what were felt to be reasonable costs. It is noted from the figure that the overall probability of detection at the 99 percent+ level for all stages requires an expenditure of $300,000 per year and gives a system reliability at the 99 percent level. The ratio of percent increase in cost to percent increase in reliability varies slowly with reliability until the system reliability reaches about 90 percent. Above P_s equals 97 percent the ratio increases asymptomatically with P_s. Between P_s equals 65 percent and P_s equals 90 percent the average ratio is unity, i.e., the percent increase in safeguards cost is roughly proportional to the percent increase in system reliability.

Vulnerability Index Model

In applying cost optimization to safeguards, the assumption of equality of all forms of nuclear materials (except wastes) is often made, i.e., all forms of fissile material are safeguarded with equal intensity. To remove this assumption, one must know the relative likeness of attempted diversions of the various forms of material, and how to incorporate this knowledge into the optimization model of the system.

Relative weights were assigned to various forms of fissile material by employing the results of the hazards survey conducted by L. H. Rappoport and J. D. Pettinelli.[1] The relative weights were incorporated into a systems model by defining a function of both the probability of detection and the relative likeliness of an attempted diversion termed the vulnerability index, defined as:

$$VI = \sum_i \pi_i y_i \quad , \tag{5}$$

where VI is the index, π_i is the diverter preference of the type of material at the safeguards point i, and y_i is the probability that a diversion at point i would **not** be detected.

This optimization model is constructed to minimize the overall cost at a given system reliability,

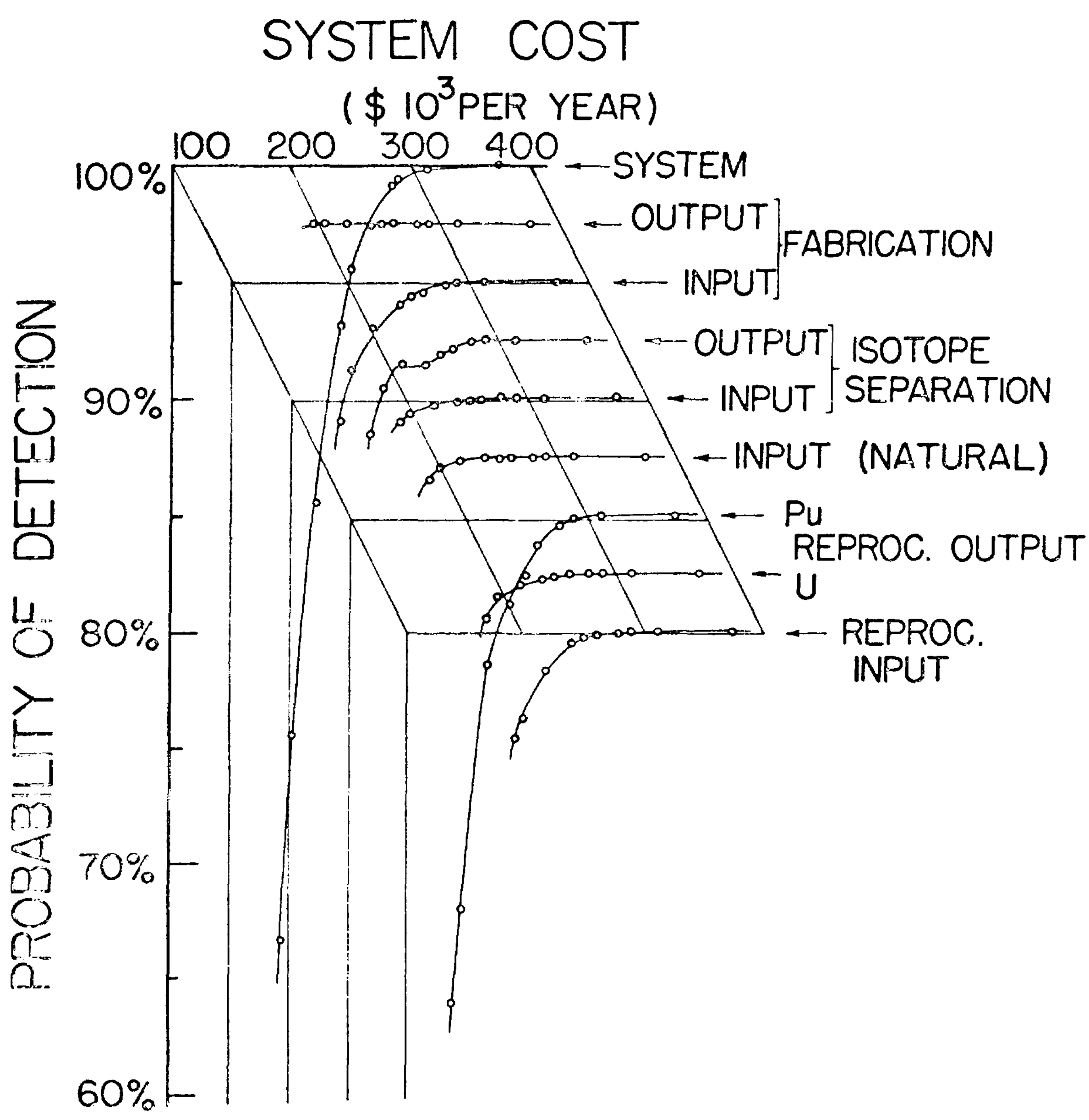
$$P_s = \prod_i P_i \tag{6}$$

subject to a vulnerability index constraint,

$$VI \leq VI^* \tag{7}$$

with the overall cost defined as:

$$C = \sum_i c_i k_i \quad . \tag{8}$$



STAGE PROBABILITY OF DETECTION vs. SYSTEM COST

Comparing the results of the vulnerability index model with the results of the optimization based on system reliability alone (following table), it was found that while the overall costs are similar, the distribution of costs was very different. The use of diverter preference placed more safeguards effort at the points where diversion was more likely to be attempted.

Non-Destructive Analysis of Dissolved Spent Fuel: A Feasibility Study

C. R. Rudy

The measurement of plutonium inputs to reprocessing plants using the relative strengths of plutonium and uranium K X-rays has been studied. A measurement of the (Pu) (U)ratio for a batch of dissolver solution together with knowledge of the total uranium per batch from fabrication specifications allows an indirect measurement of the plutonium input to a reprocessing plant.[13]

We have studied the possibility of using the uranium and plutonium K X-rays generated by the high fissions product activity intimately mixed with these actinides in dissolver solution for high burnup LWR fuels. (Details of this analysis, including the computer code used, are contained in a complete report.[14]) The K X-rays would be generated primarily by 1) photoexcitation of the actinides from low-energy gamma emitters with photon energies slightly above the K absorption edge of plutonium and 2) K-shell ionization due to the stopping of beta rays in the dissolver solution. The background in the K X-ray region due to activity in the dissolver solution consists of contributions from compton scattering of low energy gamma rays ($E_\gamma < 235$ keV) and bremsstrahlung from the beta activity in the solution.

We have calculated the contributions of all of the above processes using various integration schemes and generated artificial spectra for a dissolver sample consisting of spent fuel cooled for different periods. Such a spectrum is shown in the following figure. The primary generator of self-fluorescent K X-rays in dissolver solutions for cooling times longer than 105 days and less than several years is ^{144}Ce. This is due to its high yield, long lifetime, large gamma activity at an energy that efficiently excites actinide X-rays and to the high beta ray energy of its daughter ^{144}Pr.

The use of a bent crystal spectrometer to focus an energy band, corresponding to the X-ray region, onto a Ge(Li) or Ge detector[15] appears to be the fastest way to measure these X-rays. If the bent crystal spectrometer were to be used along with a detection device of low resolution in a scanning mode, the counting time would be at least doubled, because of the need to measure the spectrum that includes the Pu X-ray, a background, and the more prolific U X-rays. Higher energy gamma rays from the dissolver solution would induce a large compton background in a Ge detector used without a bent drystal spectrometer. This would completely mask the plutonium X-ray peaks in the original spectrum. By fixing a suitably collimated Ge detector on the focal plane of a bent crystal spectrometer in the Cauchois geometry, one no longer has the added compton background or needs the moving parts of a scanning spectrometer. The counting time necessary to obtain 1 percent statistics is about 20 hours with these instrumental conditions and with dissolver solutions 105 days old.

Shorter counting times can be obtained by use of an external fluorescing source such as ^{144}Ce. A strong source is required for either a system combining a bent crystal spectrometer with a Ge detector of a Ge detector system alone. For the former system, a 10-kilocurie ^{144}Ce source can increase the counting rate resulting in shorter counting times (1 percent statistics in 20 minutes for the Pu-U ratio), and in the latter the source can boost the Pu X-ray counting rate above the background resulting from the Compton effect with high-energy gamma rays. Since the major source of this background is relatively rapid decaying ^{95}Nb and ^{95}Zr, the latter method becomes more favorable for longer cooling times ($>$ 300 days) as a result of the improved X-ray peak-to-background ratio. With this improved ratio and with the high efficiency of a Ge detector, the counting time needed for good statistics is no longer a problem.

The above calculations were undertaken to investigate a system that required a minimum of sample manipulation. By this means, X-rays can be measured directly through the sides of sample bottles with no manipulation other than moving the samples in front of the detector. Production samples can thereby be analyzed on a batch to batch basis. One of the above techniques would provide a supplementary tool for both plant management and an inspecting agency.

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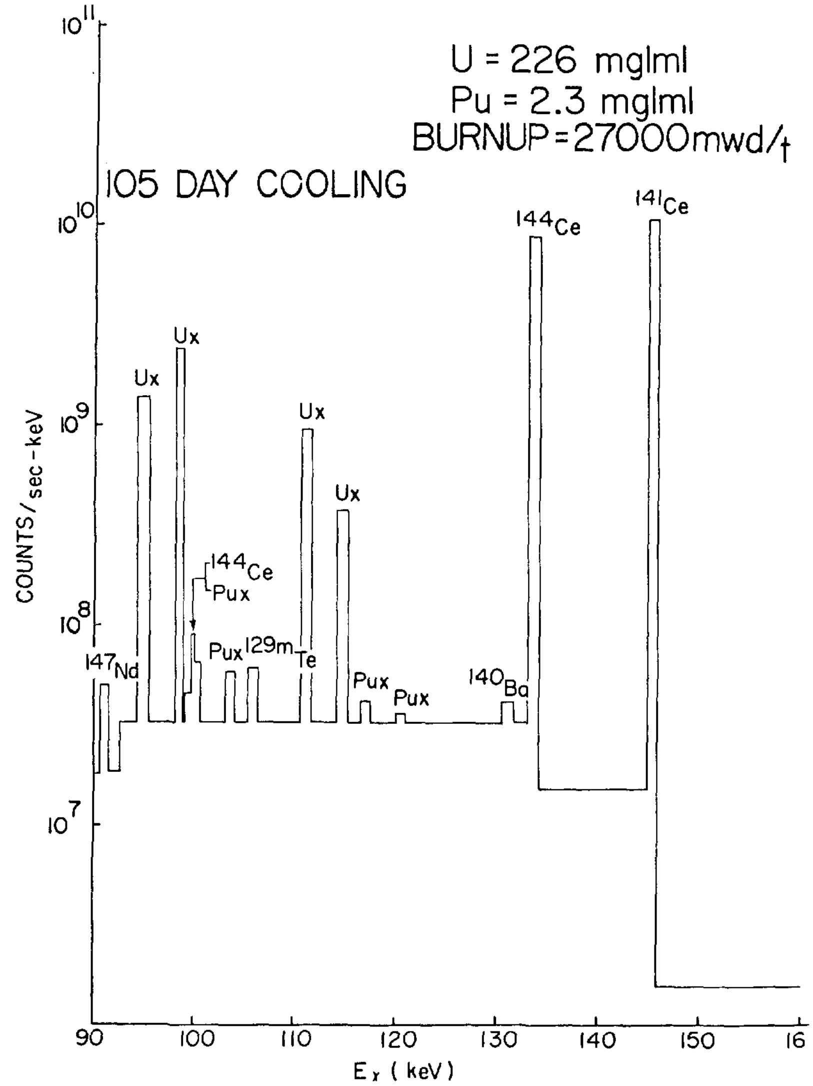

Comparison of V.I. Procedure with Straight Optimization

System Reliability (P_s)				0.6762				0.7563				0.8548			
V.I.#				(0.1009)		0.0786		(0.0755)		0.0564		(0.0432)		0.0331	
Cost*				193		208		203		217		218		230	
Safeguards Points				P_i	c_i	P_i	c_i	P_i	c_i	P_i	c_i	P_i	c_i	P_i	c_i
Reprocessor	Input	P_u	1	0.9533	13.62	0.9722	15.61	0.9625	14.47	0.9934	20.43	0.9788	16.74	0.9888	18.73
	Output	U	2	0.9816	4.64	0.9744	4.24	0.9888	5.17	0.9888	5.17	0.9936	5.67	0.9879	5.04
		P_u	3	0.8146	34.05	0.9464	54.33	0.8531	38.16	0.9483	54.86	0.9167	47.57	0.9704	62.61
Isotope Separation	Input	Nat	4	0.9921	2.30	0.9660	1.74	0.9954	2.61	0.9811	1.99	0.9974	2.86	0.9801	1.99
		1%	5	0.9917	2.43	0.9903	2.36	0.9946	2.67	0.9968	2.92	0.9969	2.92	0.9914	2.43
	Output		6	0.9607	15.83	0.8900	12.47	0.9791	17.32	0.8900	12.44	0.9890	18.57	0.9473	14.96
Fabrication	Input		7	0.9405	12.01	0.8928	9.57	0.9620	13.88	0.9562	13.32	0.9755	15.65	0.9808	16.66
	Output		8	0.9981	0.71	0.9923	0.58	0.9991	0.77	0.9757	0.46	0.9995	0.82	0.9990	0.77

#V.I. for straight optimization obtained from equation (2). V.I. for straight optimization marked ( ).

*Overall cost in thousands of dollars