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## *GUEST EDITORIAL OPINION*

**Bernard Gessiness**

# GESSINESS SPEAKS OUT

We old-timers have much to be proud of as we look back over a decade of accomplishments in the Institute. We now have some 400 members, money in the bank, a superb technical journal, one successful annual meeting after another, 70 Certified Nuclear Materials Managers, and a number of ANSI standards to our credit. The natural tendency for us now is to sit back smugly, complacently, and rest on our previous laurels. Nothing could be more harmful for the Institute than this attitude of stagnation and self-satisfaction.

There is much work to be done if the Institute is to continue as a dynamic society of professionals. We must "sell" the Institute to the utility companies who will be investing huge sums of money in nuclear fuel inventories. We must attract new members from all facets of the nuclear industry and then we must make sure that we are giving our members "their money's worth" even though they are not privileged to attend the annual meeting.

We need to restudy our objectives and determine anew our **raison d'etre**, our justification for existence. Over the years we have passed from one theme to another, paralleling AEC's current philosophy of accountability, nuclear materials control systems, safeguards, security for shipments, NMIS, audits, nondestructive testing, standards preparation and quality assurance. We no longer represent a single specialty or discipline; instead, we pretend expertise in all of these fields. Are we truly "jacks-of-all trades"? Apparently not. Otherwise, AEC and the nuclear industry would be constantly soliciting the services of our Certified Nuclear Materials Managers in the solution of the myriads of daily problems confronting them. We must pursue vigorously the dialogue with AEC which has been recently opened by our Executive Committee to gain recognition and stature for the Institute's certification program.

As I sit in my rocking chair fondly gazing at the impressive red and gold binder of my INMM manual, I am suddenly startled by the fact that it is nearly empty. When was the last time I received some timely and useful information to insert in the manual?

We need to approach the appropriate people, offices and committees of AEC, AIF and ANS periodically with constructive ideas, suggestions or proposals that will gain recognition, add prestige and solidify working relationships with these organizations. We must strengthen our weak public image by timely publicity before, during and after our annual meetings. Our members should be willing to speak locally to civic groups and thereby "advertise" the Institute.

Perhaps the time has come for us to organize regional INMM groups and meetings on the West and East coasts and, say, in Chicago or Oak

(Continued on Page 12)

**R. G. Cardwell**

# 1974 ANNUAL MEETING
## JUNE 19-21

The summer issue of the Journal arrived amid my "floundering" about for an orderly beginning to formation of the 1974 technical program for our Annual Meeting in Atlanta. Since I am now entering my third year as Technical Program Chairman, I am happy to report that I am now "floundering" with more order and less apprehension; but the magnitude of this undertaking still sobers me into a realization of the serious responsibility involved.

INMM has become **the** forum of nuclear materials management. No other organization focuses so large a number of varied techniques and specialties on the problems of this single function — and the focal point is the Annual Meeting. It is therefore extremely important that the technical program not only provide the attendees with as much current information as possible but also focus a dialogue on the more current and critical problems, hopefully placing them in their proper perspective and bringing them toward more-or-less mutually agreeable solutions (I believe the latest expression is "detente").

Unfortunately, time is always our biggest nemesis, and we suffer the proverbial problem of "packing four pounds of material in a two-pound container." I complain without hesitation that the most difficult job of our Program Committee has been to select the most appropriate papers from the many excellent abstracts proposed and fit them into the limited time available.

This is a difficult problem, but I do not believe it is insurmountable; and we shall make a special effort in 1974 to overcome it. Gene Miles, the newest member of our committee, has proposed a workshop idea which we hope to try out. If the number and quality of abstracts come in as expected, we will probably go to some concurrent sessions. These, with some other new thoughts, all afford opportunities for a significant increase in direct participation on the program.

The Call For Papers for our 1974 Annual Meeting should have reached you by this time, and I invite your comments and suggestions as well as your abstracts. — Roy G. Cardwell

## *GUEST EDITORIAL OPINION*

**Wm. J. Gallagher**

# DOLLAR ABOVE EVERYTHING ELSE?

As a former resident of the beautiful state of Connecticut, I was referred to as a "Nutmegger." It wasn't until years later that I learned that this term is synonymous with "hard Yankee trader," or one who puts the dollar first. In the days of the early American colonies, spices were at a premium and commanded a high price. During the long winters, the enterprising Connecticut farmers whittled fake nutmegs out of wood and sold them to unsuspecting travelers passing through the area. Consequently, these farmers became known as "Nutmeggers." Two hundred years later, a comparison of gold and uranium reminds me of nutmegs.

Gold and uranium are two heavy elements that are comparable in many ways. Both are extracted from the earth and are in relatively short supply; both are intrinsically valuable and are eagerly sought after; both are politically controversial; etc., etc., etc. The similarities are limited only by your imagination; however, the differences in control of these two elements are significant.

From the time gold is separated from the earth until the time it ends up as that shiny plating on your wrist watch, a continuous material balance is maintained. Gold processors do not depend upon semiannual or even quarterly inventories for materials control, and there are no advocates of "black-box" accountability systems. The quantity of gold in process, in storage, and in waste is known, not estimated. Employees in manufacturing facilities utilizing gold are screened daily upon leaving areas in which gold is stored or processed. Gold is transported within special vehicles under the control of selected, bonded personnel who may be armed. Purchasers of gold know its assay to the proverbial "gnat's eyebrow." Government Regulatory Guides are not needed for the security of gold.

Do you want the uranium comparison? If you are familiar with the handling, processing, or transportation of uranium, you already know it.

I believe that uranium is presently controlled to a lesser degree than gold because gold is more readily converted to money. Does this mean that we Americans are still Nutmeggers or hard Yankee traders who place the dollar above everything else, including Safeguards of fissile materials? What's your your opinion? — Bill Gallagher.


**W. F. Heine**


**J. L. Jaech**


**J. D. Moore**


**S. H. Smiley**

## AUTHORS FOR WINTER 1974

**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.

**J. L. Jaech** (B.S., Mathematics, M.S., Mathematical Statistics, University of Washington). Staff Consultant, Statistics, Exxon Nuclear Company, Richland, Wash. Jaech has been a statistical consultant in the nuclear field for 20 years. He is chairman of the INMM sponsored ANSI Subcommittee on Statistics. He has authored 16 open literature publications on statistical methods and applications in various journals.

**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 of all AI facilities.

**Seymour H. Smiley** is the Deputy Director for Fuels and Materials in the Atomic Energy Commission's Directorate of Licensing. He is responsible for licensing the use of reactor-produced radioisotopes in industry, medicine, agriculture and education, and for licensing the construction and operation of all fuel cycle plants including uranium mills, $UF_6$ plants, uranium and plutonium processing and fabrication plants, fuel reprocessing plants and waste disposal facilities. His responsibilities include licensing the export of reactors and other nuclear energy facilities and materials, and administration of the agreements under which states regulate certain nuclear energy materials and facilities within their boundaries. In 1944, Mr. Smiley joined the wartime Manhattan Engineer District at the Kellex Corporation in New Jersey where he worked mainly on problems associated with the gaseous diffusion process. He transferred in 1945 to the Government's K-25 gaseous diffusion plant at Oak Ridge, Tennessee, where he directed many important programs associated with the development of the uranium enrichment processes. He was appointed Superintendent of Engineering Development and Reprocessing in 1953 and served as a member of the senior management and technical staff at K-25. Mr. Smiley left Oak Ridge in 1967 to join Nuclear Materials and Equipment Corporation as Manager of Research and Development. He joined the AEC in his present position in 1971.

## ADVERTISING INDEX

# NEWS

## NOTICE TO MEMBERS

At its September meeting the executive committee of the Institute gave the treasurer the authority to drop from the membership rolls any member whose dues have not been paid by the end of the current fiscal year. The executive committee does not wish to reduce the Institute membership but neither does it wish to carry inactive members at the expense of those conscientious members who do support their Institute by paying their dues on time.

## CURRY APPOINTED AT N.F.S.

ROCKVILLE, Md. — Robert V. Curry was recently elected Executive Vice President of Nuclear Fuel Services, Inc.

Curry, 44, formerly executive assistant to vice president of marketing & manufacturing of Getty Oil Company at Los Angeles has been working closely with NFS for the past several months and is familiar with its goals.

Curry is coordinating the operating line activities of NFS at its Erwin, Tenn. Manufacturing Plant and its West Valley, N.Y. reprocessing plant.

A native of New York City, Curry earned his degree in civil engineering at Villanova University and continued graduate studies there. He is a registered professional engineer in Delaware and Pennsylvania.

## NEW MEMBERS OF I.N.M.M.

The following individuals have been accepted into INMM membership as of January 15, 1974. To each, the INMM Executive Committee extends congratulations. New members not *mentioned in this issue of the Journal will* be published in the Spring 1974 (Vol. III, No. 1) issue to be mailed in late April or early May.

Dr. Alfred R. Anderson, Nuclear Materials Accounting Control Team, Didcot, Berks., United Kingdom; Charles H. Bean, Argonne National Laboratory, Argonne, Ill.; Warner A. Blyckert, Richland, Wash.; Byron F. Disselhorst, Solana Beach, Calif.; Edward L. Eckfeld, Nuclear Fuel Services, Inc., Erwin, Tenn.; Dr. Daniel E. Heagerty, Gulf Energy & Environmental Systems, San Diego, Calif.; Kenneth D. Hensley, Erwin, Tenn.; Paul N. McCreery, NL Industries, Inc., Wilmington, Del.; Dwight C. Pound, Gulf Energy & Environmental Systems, San Diego, Calif.; Theodore S. Sherr, U.S. Atomic Energy Commission, Washington, D.C.; Arthur B. Shuck, Winfield, Ill.; Kirkland B. Stewart, Battelle, Richland, Washington; Matthew C. Suwala, Ford City, Penn.; W. Hord Tipton, Union Carbide Coporation, Oak Ridge, Tenn.; Hans J. Weber, Intelcom Rad Tech, San Diego, Calif.; Tom C. Westmoreland, AVCO Corporation, Tulsa, Okla.; Dr. Daniel R. Wilkins, General Electric Company, San Jose, Calif.

## N15 REPORT

**R. L. Delnay, Chairman ANSI, N15**

Much has happened since our last annual meeting. To date, American National Standards Institute has approved the nine standards that N15 has submitted for approval. Eight of the standards are published. Subcommittees and task groups are working on another sixteen proposed standards, making a total of 25 standards under N15. Currently, of the nine N15 standards, five serve as the basis for Division 5 Regulatory Guides, issued by Directorate of Regulatory Standards, USAEC.

Last Fall the Directorate of Regulatory Standards asked N15 to prepare ten standards. A review of the ten requested standards showed that six were within the scopes of N15, and four were not considered to be within the scope of N15 nor within the expertise of INMM's members. The following are the six standards which were within the N15 scope.

N15.16 — Limit of Error Concepts and Principles of Calculation in Nuclear Materials Control.

N15.23 — Nondestructive Assay of the Fissile Content of Low-Enriched Uranium Fuel Rods.

N15.24 — Standard for the Recordkeeping and Reporting of Licensee Inventory Data.

N15.25 — Standard for Measuring Material in Process Equipment.

N15.26 — Standard for Material Protection Considerations in Plutonium Scrap Recovery.

N15.27 — Standard for Material Protection Consideration in Uranium Scrap Recovery.

Proposed standard N15.16 was assigned to John Jaech's subcommittee on statistics. Lynn Hurst is the chairman of a new subcommittee created to write N15.23. The subcommittee on record, chaired by Russ Weber, assumed responsiblity for N15.24. Doug George's subcommittee on inventory techniques will prepare N15.25. Another new subcommittee was formed to write both N15.26 and N15.27. Dan Wilkins volunteered to be the chairman of the new subcommittee.

At our N15 committee meeting in May, we expanded the scope for N15 activities to cover the physical protection of special nuclear materials. The scope of N15 now reads, "Standards for management (protection, control, and accountability) of special nuclear materials in all phases of the nuclear fuel cycle, including analytical procedures where necessary and special to this purpose."

At the request of American National Standards Institute, we conducted a survey of additional professional organizations to determine if any were interested in sitting in on N15. We canvassed fourteen organizations. As a result of this canvass, representation on N15 increased by three, for a total of fifteen voting members.

As chairman of N15, I have requested that the National Bureau of Standards provide a primary radioactive heat source standard using Plutonium-238. The request was made in June, 1973. Such a primary standard will be necessary to implement an N15 standard being prepared.

## NFS ANNOUNCES BIG CONTRACT

Rockville, Md. — Nuclear Fuel Services announced it has signed a contract valued at approximately $4 million to provide transportation and nuclear fuel reprocessing services for the Beaver Valley No. 1 Unit, an 856 megawatt electric generating unit being built at Shippingport, Pa. The unit is jointly owned by Duquesne Light, Ohio Edison and Pennsylvania Power Company as part of the CAPCO power pool.

Beaver Valley Unit No. 1 is scheduled for commercial operation in 1975. Under normal operating conditions, Beaver Valley Unit No. 1 will have some of its fuel available for reprocessing in 1977.

NFS will transport the fuel to, and reprocess the spent fuel at its West Valley, N.Y., Reprocessing Facility.

LETTER TO EDITOR

# COMMENT BY LOVETT

Editor:

It appears that at least one more letter is needed in the 1970/71 Norton-Lovett exchange. The alternative is to leave your readers wondering where Jim Lovett learned his statistics, so they can be careful to choose a different school.

Certainly if one looks at a material balance period of one year, the uncertainty is not affected by any intermediate monthly inventories that may have been taken. My question was, and still is, if the intermediate inventories were going to be ignored, why were they taken? I believed then, and I still believe, that if monthly inventories are taken, then practical and political considerations will force the safeguards inspector to limit his consideration to short term, if not monthly, results.

The following example was admittedly manufactured to prove a point, but the data does not look particularly unreasonable to me. Assume that monthly inventories are taken, and that the monthly MUF's are 1.9, 0.3, -0.9, 1.0, 1.8, -0.1, 1.7, 1.0, 2.1, -1.7, 1.2, and 1.7. Assume further that the uncertainty in any inventory is + 3, and in any month's receipts and shipments is + 2. The first sign of "trouble" is after month eight, when a test of months four through eight shows that the average MUF is significantly different from zero. The same test applied to months one through eight is borderline. The MUF for month eight itself is within the calculated uncertainty, as is the MUF for any cumulative material balance period ending with month eight.

There are further indications of trouble after month nine. The cumulative MUFs for months four through nine and five through nine are greater than the corresponding uncertainties. The average MUFs for the same periods are also significantly greater than zero, as is the average MUF for the first nine months.

After ten months the situation is confused. The average MUF is no longer significant, and the cumulative MUF for ten months no longer exceeds the corresponding uncertainty. The cumulative MUFs for eleven months and for twelve months exceed the corresponding uncertainty, and the average MUF is significant after twelve months but not after eleven.

Now my point, admittedly too briefly presented in 1971, is this. If only the two annual inventories had been taken, there would have been one MUF of 10.0 and one uncertainty of + 8.1. Clearly further investigation is warranted. With eleven intermediate inventories, however, there are 144 possible statistical tests (78 individual or cumulative MUF's plus 66 tests of average MUF). Some of them say that investigation is warranted, but many of them do not. The safeguards statistician, moreover, is not free to pick and choose, discarding those tests that do not support his intuitive judgement. He must use all the data he has, or state why he rejects some of it. Once rejected, the data must stay rejected. It cannot suddenly look much better a month later.

What did the monthly inventories accomplish, then? They showed that the year-end MUF of 10.0 could not have resulted from a single diversion of that amount. They showed that there may be an unrecognized loss mechanism of about 0.83 units per month. The evidence for this latter is not completely clear, however. The monthly inventories provided timely evidence that diversion of as little as 2 or 3 units per month was not occurring. These are positive accomplishments, not to be passed over too lightly. On the negative side, however, they may have increased inventory costs by a factor of 6.0, and they gave the facility operator enough statistical data to support an argument that nothing really is wrong. (For example, at month twelve, the cumulative MUF for the last seven months and the average MUF for the last seven months are both "nonsignificant.")

To my mind, monthly inventories are at best a mixed blessing. More accurate inventories I will vote for anytime. More frequent than annual I will also vote for. More frequent than quarterly I will vote for only in special cases, where the benefits (less the dubious benefits) appear to justify the effort.

Jim Lovett
Vienna, Austria

FOR CNMM'S

## PHOTO AVAILABLE

Editor:

Please inform your readers that 8 x 10 glossy prints of the picture of the Certified Nuclear Materials Managers in the summer issue (p. 7) are available from Blake Photo Service, Room 201, U. S. Grant Hotel, San Diego, California 92101. Ask for Photo No. NM-26. The price is $2.50 per print plus 25 cents for each mailing.

Roy Cardwell
Oak Ridge, Tenn.

## ADDRESS CHANGES OF INMM MEMBERS

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

Richard A. Alto, Manager, Manufacturing, Babcock & Wilcox Company (CNFP), P.O. Box 1260, Lynchburg, VA 24505; Dr. Richard L. Bramblett, Intelcom Rad Tech, P.O. Box 80817, San Diego, CA 92138; John H. Cappis, 30 Glenview Court, Los Alamos, NM 87544; Ira Cohen, U.S.A.E.C., 631 Park Ave., King of Prussia, PA 19406; Thomas J. Collopy, United Nuclear Corp., 67 Sandy Desert Road, Uncasville, CT 06382; John M. Crawford, 446 Love Street, Erwin, TN 37650; Delmar L. Crowsen, Middle South Services, Inc., P.O. Box 61000, New Orleans, LA 70161; John L. Curtis, Florida Power and Light Company, P.O. Box 3100, Miami, FL 33101; Donald E. Curran, Federal Power Commission, 825 North Capitol Street, N.E., Washington, D.C. 20426; V.J. D'Amico, U.S.A.E.C., Oak Ridge Operations Office, P.O. Box E, Oak Ridge, TN 37830; Robert Delnay, 6119 Perrine Road, Midland, MI 48640; Philip B. Fisk, 1428 Agnes Street, Richland, WA 99352; William J. Gallagher, Intelcom Rad Tech, P.O. Box 80817, San Diego, CA 92138; Gordon Hough, 2401 West Canal Drive, Apt. 4B, Kennewick, WA 99336; Jon H. Jennekens, Director, Nuclear Plant Licensing Directorate, Atomic Energy Control Board, P.O. Box 1046, Ottawa, Canada, KIP 559; Edwin M. Kinderman, 1548 Hudson Street, Apt. 201, Redwood City, CA 94061; Dr. Herbert J.C. Kouts, U.S.A.E.C., Washington, D.C. 20545; James W. Lee, Transportation Consultant, P.O. Box 14336, N. Palm Beach, FL 33408; Harvey B. Lermack, Gulf United Nuclear Fuels Corporation, Fabrication Operations, P.O. Box 605, New Haven, CT 06503; John Mangusi, Transnuclear, Inc., Skyline Center, 5205 Leesburgh Pike, Baileys Crossroads, VA 22041; Walter G. Martin, U.S.A.E.C., 631 Park Ave., King of Prussia, PA 19406; Dr. Arthur R. Matheson, R2-M3, Del Mar, CA 92014; Edward J. McAlphine, General Electric, MC-159, 175 Curtner Avenue, San Jose, CA 95125; Emanuel R. Morgan, 520 Princeton Drive, King of Prussia, PA 19406; S. G. Nordlinger, 1620 S. Ocean Blvd.— No. 4A, Pompano Beach, FL 33062; V. N. Rizzolo, 1354 Campus Drive, Berkeley, CA 94708; Dr. David E. Rundquist, Intelcom Rad Tech, P.O. Box 80817, San Diego, CA 92138; Marvin R. Schneller, 2204 West 1st Avenue, Spokane, WA 99204; Lewis C. Solem, Directorate of Regulatory Operations, Office of Regulation, U.S. Atomic Energy Commission, Washington, D.C. 20545; Ella C. Werner, Apt. 1615, Plymouth Harbor, 700 John Ringling Road, Sarasota, FL 33577.

# LOW NAMED NuSAC VICE PRESIDENT

Falls Church, Va. — NuSAC has announced the appointment of Lawrence D. (Dave) Low as a vice president. In this capacity, Low is responsible for newly-established NuSAC services to the nuclear industry in materials and plant protection.

These services include preparation of plans and programs for the physical protection of nuclear power plants, reprocessing plants, and fuel fabrication facilities against industrial sabotage, and protection of special nuclear material, on site or in transit, against theft or diversion; the conduct of audits of on-going protection programs; and assistance to AEC licensees on physical protection licensing and compliance problems.

Low has been active as a consultant on industrial security for nuclear facilities since his retirement from the USAEC in June, 1972. During his 25 years of AEC service, he was the director, Division of Compliance (re-named Directorate of Regulatory Operation) and prior to 1960 he was director, Division of Security at the AEC Operations' Office in Aiken, S. C., during the design, construction, and initial operations of the Savannah River plants.

# QUALITY ASSURANCE IN THE NUCLEAR FUEL CYCLE

**Seymour H. Smiley**
Deputy Director for Fuels and Materials
Directorate of Licensing
U.S. Atomic Energy Commission
Washington, D.C.

### Introduction

The public is constantly reminded of the serious consequences of accidents or failures in nuclear plants. Charged with responsibility for protecting the public health and safety, the U.S. Atomic Energy Commission (AEC) has the objective of providing leadership in giving the world the benefits of nuclear energy in a manner that affords greatest assurance of safety and reliability. There is no better way to assure safety and reliability in nuclear energy plants than to place major, unremitting emphasis on quality assurance in every aspect of the business.

Today's advanced technology has been proven in many tests to be capable of achieving the standards of quality and performance required for nuclear plants. Clearly, the success of nuclear ventures depends strongly upon applying the technology properly and with good quality workmanship so that the first time, or the nth time, the equipment is used it will operate as it is intended to operate — with no leaks, no losses, no radiation exposures — in short, no hazards to health, safety, or national security.

Quality assurance (QA) is a planned program of actions involving every level of management and covering every aspect of nuclear operations to guarantee that facilities and equipment are designed and built to work right and are operated in the manner intended. The assurance of quality comes from providing a system of controls to assure that every step is performed correctly and that records are kept to prove it. The quality assurance records must be complete and must be kept in a form and condition suitable for auditing. The essence of quality assurance, then, is action — working carefully to be sure that things are right.

### The Importance of Quality Assurance

Today's technology of nuclear energy provides acceptable solutions to the problems of design, construction, operation, and protection of nuclear fuel cycle facilities — which is not to say that no further improvements are desired, but rather that proper application of available technology will meet acceptable standards. The broad QA objective, then, is to assure high standards of performance in the application of the available technology so that things will be built and will perform in accordance with the design criteria and specifications.

Quality assurance specifies what the available technology should be expected to accomplish and monitors actual performance to assure attainment of the expected results.

The Atomic Energy Commission, keenly aware of its responsibility for the security of nuclear materials and facilities and for protecting public health and safety, considers quality assurance to be extremely important, and its implementation to be a key aspect of successful operations. The seriousness with which the Atomic Energy Commission pursues the quality assurance objectives is shown by last year's five regional conferences in which Commissioners Doub and Larson and the Director of Regulation, L. Manning Muntzing, and key members of his staff, met with utility industry leaders to stress the need for improvement in quality assurance programs implementation.

The well-known Appendix B to Title 10, Part 50, of the Code of Federal Regulations covers "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." It provides the following definition and describes the major features of a good quality assurance program:

**Quality assurance comprises all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. Quality assurance includes quality control actions related to physical characteristics which are important in determining that the quality of the material, system, component, or structure meets the requirements.**

Appendix B establishes the requirements for quality assurance in the design, construction, and operation of nuclear power and fuel cycle plants, particularly with respect to the structures, systems, and components that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. These quality assurance requirements are intended to assure that:

(a) Applicable regulatory requirements and the accepted design criteria for structures, systems, and components are correctly translated into specifications, drawings, procedures, and instructions.

(b) Systems and components fabricated and tested in manufacturers' facilities conform to the specifications, drawings, procedures, and instructions.

(c) Structures, systems, and components constructed and tested at the nuclear power plant site conform to the specifications, drawings, procedures, and instructions.

(d) Succeeding activities, such as operating, testing, refueling, repairing, maintaining, and modifying nuclear power plants, are conducted in accordance with quality assurance practices consistent with those employed during design and construction.[1]

A quality assurance program is a system that is devised to be certain that these actions are taken. On the basis of experience, the content of a good quality assurance program is now well established, and applicants for AEC licenses are improving the quality assurance programs they describe in their submissions accompanying the preliminary safety analysis report. It is the implementation of quality assurance programs that needs additional emphasis and attention, especially since the AEC is relying heavily on improved quality assurance implementation to reduce the frequency with which malfunctions are being experienced, to eliminate the deficiencies in operating and maintenance practices that have been discovered through AEC's compliance inspections in the field, and to eliminate the infractions of AEC regulatory requirements. The designers, builders, suppliers, and operators in the nuclear industry are being urged to organize their functions and line authority to carry out tough QA implementation programs.[2,3] Some already have, and under the June 1973 revised Regulatory Procedures, all organizations will be given earlier field inspections of their QA implementation actions as a part of the preliminary review prior to docketing the application for a Construction Permit.

There are two main aspects of quality assurance in the nuclear fuel cycle. One relates to the design, construction, and operation of the fuel fabrication, spent fuel reprocessing and other fuel cycle plants; the other relates to the design and fabrication of the fuel and its performance in the reactors.

### QA For Plant Design, Construction, and Operation

The first major application of QA in the fuel cycle begins with design and construction of fuel cycle plants and continues through all stages of operation, maintenance, alteration, and expansion. Responsibility for review and evaluation of fuel cycle quality assurance programs lies with the Deputy Director for Fuels and Materials, Directorate of Licensing. The primary emphasis in QA is to assure that design objectives are fulfilled correctly in the structures, systems, and components that are important to safety and to special nuclear materials protection so that the health and safety of the public and employees are protected, the environmental values are preserved, and the common defense and security are assured. In the past, quality assurance programs have too often been developed after the design of the plant was well advanced. Quality assurance should start with the inception of design work. The benefits of quality assurance efforts at the design stage can be especially significant for nuclear materials management.

### Development of Design Criteria

Generally, operating companies depend on outside assistance from engineering firms for most of the efforts involved in major design and construction programs. However, the planning and the development of basic criteria, which are the first steps in a plant design program, will usually be the responsibility of the operating company's own technical and operational staffs. They are the skilled personnel who are best qualified to reduce the program goals and objectives to the bases needed to tell the designers what is required. Therefore, it is important the in-house team do its homework well before the designers become involved. Forethought and planning at this time can facilitate subsequent performance of the functions of nuclear materials management.

To assist in the development of the design bases, the Commission is preparing a series of general design criteria for fuel fabrication facilities and reprocessing plants patterned after the criteria for reactors which appear in Appendix A of Part 50. The new criteria will cover materials and plant protection as well as health and safety.[4]

### Preliminary Design

After establishing design criteria, including provisions for QA, the team is ready for the preliminary design required to proceed with an application for a construction permit. At this juncture, the project team must translate the criteria into preliminary plans and concepts to define some of the specifics of the plant and equipment. The question is always posed, "How far does one go in preliminary engineering and design?" From the AEC's standpoint, a satisfactory answer is that the preliminary work must include sufficient detail to realistically define all major safety, safeguards and environmental impact issues and to establish a plan for dealing with them.[5]

The culmination of the preconstruction phase is the submittal of the license application and the environmental report by the applicant. These documents serve as the basis for decision making and must be prepared in a meticulous and thorough fashion. Quality and completeness in these submittals cannot be overemphasized. Well developed and substantial reports will speed up the licensing and environmental review processes. Recommended courses of action should be justified and supported by engineering analyses of alternatives. The rationale for decision making should be thoroughly explained and should be clearly and concisely presented. Once again, quality assurance efforts are necessary to verify that all criteria and standards have been carefully considered and implemented in the final documents and that these documents are indeed responsive to the regulatory requirements.

### Detail Design

The detail design involves the biggest portion of the design manpower expenditure. However, when sufficient effort and ingenuity have been employed in the prior phases, this activity deals primarily with details and specifics rather than principles or basics. More and more it is being recognized that it is desirable to include greater detail in the construction permit application and in the environmental report because this significantly aids the licensing review. Throughout the detail design stage, extensive application of quality assurance is necessary to make sure that the criteria, standards, preliminary designs and concepts are realistically and meaningfully carried out in the detailed plans and specifications. It is essential that the intent of all design bases and criteria be translated into structures, equipment, and systems to provide the desired results. During detail engineering, care must be taken to define and fully explain those changes which deviate from original criteria or preconstruction bases. These must be clearly described in an amendment to the license application, and if they affect environmental considerations, must be included in revisions of the Environmental Report.

### Construction

During the construction phase, the quality assurance program must be fully implemented. The equipment must be fabricated and installed to meet the requirements of all portions of the planning and design activities. The entire facility must be rigorously reviewed, inspected, and tested to assure that the quality required by the criteria, standards, and designs has in fact been built into the working facility. Only in this manner can a properly functioning plant be turned over to operations with reasonable assurance that it can be put on stream with minimum potential for hazard to the operating personnel, the public, or the environment with assurance that the special nuclear material is adequately controlled and protected.

### Operation

Companies which design, construct, and operate nuclear facilities have generally become quite familiar with QA requirements for plant construction. There is evidence from AEC inspections, however, that in some plants the QA program stops or is relaxed after the plant has been designed and constructed. Obviously this practice will eventually lead to problems. QA must be continued for operations and maintenance during the life of the plant. The same basic elements that are important during design and construction are important when the plant is in operation, particularly when accomplishing plant modification. QA during operations is a long-term effort that requires continuous top-level management, emphasis and support to be and remain effective.

### QA for Fuel

In the AEC's Regulatory organization, responsibility for review of QA for reactor fuel preformance rests with the Deputy Director for Technical Review, Directorate of Licensing. Each applicant for a construction permit or operating license for a nuclear power reactor must include in his Safety Analysis Report information on the mechanical design of the fuel to be used and a description of the quality assurance program applicable to the reactor fuel. This information is reviewed and evaluated by the AEC to verify that the QA program related to design specifications, materials selection, manufacturing procedures, and testing and inspection of fuel is adequate to give real assurance of long-term reliability and mechanical integrity. The 1973 revision of the Regulatory procedures calls for the preliminary review of applications for construction permits to include a detailed review by the Directorate of Licensing of the quality assurance program description as it applies to design and procurement activities. It also calls for an inspection by the Regulatory Operations Regional Offices of the implementation of the quality assurance program for these activities. This quality assurance program review and inspection will generally be performed within 30 days after receipt of the application.[6] Important areas which will be reviewed in determining the adequacy of quality assurance for nuclear fuel are the following:

1. **The fuel design criteria established to meet normal operational effects of burnup, fission gas release, uniform and non-uniform thermal expansion, clad strain, and corrosion.** Each fuel component, i.e., pellets, cladding, and hardware, is evaluated in terms of its particular characteristics. For example, the chemical, dimensional, and integrity characteristics of pellets are evaluated in terms of the specifications governing oxygen-to-uranium ratio, moisture content, impurities, diameter, porosity, density, cracks, and chips. The cladding and other metallic hardware component evaluations include mechanical and metallurgical characteristics as well.
2. **The manufacturing process controls which assure an acceptable end product.** Process controls are evaluated for all aspects of the manufacturing process, especially for the important steps of fuel conversion, pressing into pellets, sintering, and grinding, cladding fabrication, fuel rod loading with checks and controls on moisture and hydrogenous material, end plug welding, spacer grid manufacture including forming, welding, and brazing, and the final fuel assembly manufacture including rod identification and orientation, bundle orientation in core, handling, storage, and packaging. Implementation inspections also cover the actions taken to maintain materials traceability and to assure the acceptability of reworked fuel components.
3. **Tests and inspections performed to assure product quality.** This includes evaluation of the adequacy of sampling plans, review of the criteria for quality acceptance and review of the specifications for the sensitivity and accuracy of measuring devices. A statistical evaluation of the test results on known samples run as controls should be included to determine the sources of errors in testing and inspection and to detect drifts in calibration.[7]

All of this information is reviewed and evaluated to verify that the quality assurance and quality control activities in design and manufacturing are adequate to assure the long-term integrity of the fuel element from fission product leakage. In addition, an evaluation will be made to determine whether the fuel design and manufacturing techniques will minimize, to an acceptable degree (i.e., 0.1 percent) fuel failures caused by internal contaminants, pellet/clad interaction, corrosion, fretting and wear, manufacturing defects, and pellet densification.

### QA Field Inspections

Once an acceptable QA program has been established, the responsibility for reviewing and evaluating the implementation of the program during actual fuel fabrication rests jointly with the licensee's management and with the AEC's Directorate of Regulatory Operations. Important aspects of the QA program which will be evaluated during plant inspections are the following:

1. **Management implementation of the QA program.** This includes an overall audit of the QA activities including the adequacy of subvendors' programs. In addition, the functional responsibilities of the QA organization are evaluated by determining whether the appropriate checks and balances and internal controls are being implemented. Other aspects of the QA program, such as actions taken regarding nonconforming items and the level of maintenance and calibration of inspection equipment, may also be reviewed.
2. **The application of the QA program to off-site component manufacturers.** Audits made at vendor or subvendor facilities are reviewed with particular emphasis on the manufacturer's process controls, testing procedures, and qualifications of test parts. An evaluation of component and material quality, as indicated by conformance to specifications, is also included.
3. **In-plant QA activities.** Inspectors review both the actions taken and the documentation related to receipt, inspection and testing of components manufactured off-site, manufacture and inspection of pellets, fuel rod loading, welding, identification, and testing, grid manufacture and inspection, and fuel bundle assembly, inspection, storage, and packaging for shipment. The AEC intends for the inspections of in-plant activity to be an in-depth evaluation of how the fuel fabricator is meeting all the requirements expressed in drawings, specifications, manufacturing process controls or limits, tests, and inspection procedures. The inspections are intended to determine whether current operations comply with requirements; the fabricator is expected to demonstrate, through well-documented records, that his past operations have been in compliance with all requirements.

### QA Organization and Administrative Procedures

There are some basic procedures and principles which are considered by the AEC to be important in establishing and executing a quality asssurance program for plant operations. The AEC checks to see that these are included in license applications which are being evaluated and the AEC also includes them as a part of the license specifications. In certain cases, the AEC has added safeguards amendments to existing licenses, setting forth specific license conditions which define the QA program in the safeguards area.

Appendix B on Quality Assurance Criteria points out that "the assurance of quality requires management measures which provide that the individual or group assigned the responsibility for checking, auditing, inspecting, or otherwise verifying that an activity has been correctly performed is independent of the individual or group directly responsible for performing the activity." The ANSI Standard N45.2-1971 on quality assurance states:

**"Persons and organizations performing quality assurance**

**functions shall have sufficient authority and organizational freedom to identify quality problems; to initiate, recommend, or provide solutions through designated channels; to verify implementation of solutions; and to control further processing, delivery, or installation of a nonconforming item, deficiency, or unsatisfactory condition until proper dispositioning has occurred."**[8]

Certainly the QA organization must be situated high enough in the total organization to have the needed authority and to have independence from the compelling influences of production. It must also have the benefit of direct and continuing participation by the highest levels of management, who must demonstrate a positive attitude and commitment to quality assurance that will permeate the entire organization. There is no escape from this requirement; quality assurance is not negotiable — either the organization gets everybody on board and obtains assurance of quality, or it doesn't have it.

Administrative procedures establish the basic management ground rules by which the plant should operate. They establish the organization, define lines of responsibility and authority, establish duties and qualifications of personnel and define the requirements placed on operations and operators. Effective working of the organization, its management, and its procedures will produce the extra margin of care and attention to detail needed to achieve quality assurance. There are increasing indications that this is "an idea whose time has come" for all high-technology industries; there is no question that the AEC is determined to have quality assurance in nuclear power plants and fuel cycle facilities.[9]

### QA Implementation

Genuine interest in quality assurance from top management through all levels provides effective motivation for implementation of the quality assurance program; and proper implementation is what we must have for effective quality assurance, especially in the nuclear fuel cycle. Even on a strictly economic basis, effective QA implementation yields improvements in the on-stream time of the plant by reducing the costly shutdowns, decontaminations, radiation control precautions and other complications so often associated with component failures in fuel cycle processes. It is easily possible for one worker's poor workmanship to result in a failure which costs more than his entire lifetime earnings, not to mention the risks to health, safety, and security which might be associated with such a failure.[10]

Such is the importance of good QA implementation that a comprehensive audit system is essential to verify compliance with all aspects of the program and to determine its overall effectiveness. The audit results must be documented and reported to management, with appropriate followup action including re-audit of deficient areas. Here again, the attitude of top management will be vitally important in determining how thorough an audit is performed, how prompt and effective the follow-up will be, and how soon the benefits of the audit will be reflected in improved assurance of quality.

L. Manning Muntzing, the AEC Director of Regulation, recently commented, "We note with satisfaction that a number of utilities are beginning to apply AEC quality assurance requirements to their fossil plants." He then went on to emphasize the importance which the AEC places on quality assurance,

**"If nuclear power is to make its predicted contribution in the energy field, it must be able to win public acceptance. To do this, it must achieve a spectacularly successful safety record. Without effective quality assurance, nuclear power is not likely to achieve this demanding gaol."**[11]

### Quality Assurance in Nuclear Materials Management

Nuclear materials management responsibilities can be carried out much more readily and effectively in material balance areas which have had the benefit of QA emphasis from the beginning of preliminary design through all subsequent phases. It is commonplace for safety engineers as well as process engineers to contribute important guidance to the designers. In the same manner, nuclear materials managers should participate from the beginning of preliminary design to specify the features required for improving QA in the accounting and protection of special nuclear materials.

As an important example, nuclear materials managers can recognize weaknesses in processing systems that tend to increase the material unaccounted for (MUF) in material balances. Considerations of these problems in the course of preliminary design should lead to design features which give greater assurance of quality. Because the sampling of process materials is complicated by the requirements of the processing operations, special emphasis is needed to communicate to the designers an appropriate concern for improving the accuracy with which one can obtain representative samples and can determine the quantity of material from which the sample was drawn.

In addition, the nuclear material manager must provide for the measurements and analytical performance to be checked through a quality control process in which current results on known control samples are compared to performance standards set for quality assurance in the measurement and analytical processes. Deviations beyond the standard control limits and unfavorable performance trends should be reported to management for consideration of corrective action. Continuing programs of measurement calibration, quality testing, and data analysis must be designed and implemented to monitor quality performance and to provide data for the calculation of limits of errors for measurements.

Good quality assurance in physical protection shows up in important ways: alarms work the way they are intended, detectors and devices for surveillance provide reliable monitoring of key areas, and communications get through. It is vital that the structures, systems and equipment perform properly when challenged. At times, the effectiveness of physical protection depends entirely upon the quality of the physical barriers surrounding protected areas, upon the intrusion alarms for detecting unauthorized entry, the systems for communication with law enforcement authorities, radiation measuring equipment for detecting concealed SNM, and the equipment for observing individuals who have access to special nuclear material.

Process equipment designs can enhance physical protection of special nuclear material and can also aid in the prompt detection of losses or unauthorized transfers. In the areas of nuclear materials management, as in the areas of process design, construction, and operation, implementation of the quality assurance program is the key to accomplishing the objectives.

### Conclusions

Because the energy shortage arising from inadequate supplies of petroleum and natural gas fuels has dramatically emphasized our need for nuclear power, the President has requested that the lead time for nuclear power plants be reduced from 10 years to 6 years. The AEC regulatory objective is to accomplish this without sacrificing safety, which means quality assurance. Indeed, the AEC's announced policy is to increase the emphasis on quality assurance, and especially on the implementation of quality assurance programs. Mr. Muntzing points out, "the thrust of regulation in the interest of safety must be prevention, as well as correction. The 'fix-it-if-it-is-wrong' approach, which may be standard and even acceptable in other technologies, is not acceptable in nuclear power plants. For nuclear power plants, we must have a different philosophy, namely: 'Make certain it is right in the first place.' Quality assurance is the means to this vital goal."[11] The final assurance of quality must come from the job we do in putting our QA programs into effect — implementation is the key.

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# GESSINESS SPEAKS OUT

**(Continued from Page 1)**

Ridge. A regional mini-meeting six months after (or before) the annual meeting may be a stimulating force to bind together an increasing membership which cannot always attend the annual meeting at the far corners of the country.

We need to cultivate greater participation by our members from foreign countries, particularly Canada. Perhaps we should consider holding an annual meeting in Toronto or Montreal. We should initiate a campaign to make sure that every AEC contractor, licensee, utility company and university library subscribes to our technical journal; it's the best publicity we can get. We must continue our work in the nuclear standards committees and give due recognition to those individuals in the Institute who give so much of their time and energy in these efforts.

Yes, there is much that we can do to improve the Institute in the years to come. But I and my peers, the leaders of long ago, are too tired, too preoccupied, too stale to bring these idyllic dreams to reality. We desperately need new, young, fresh, vibrant leaders; we need you! We ask you to contact the present officers and Executive Committee, offer your ideas and your services in behalf of the Institute. You'll be glad you did. Then, someday, you too can sit back and reminisce in fond recollection as I have been doing. Thank you for letting me share my thoughts with you. — Bernard Gessiness, Cincinnati, Ohio, INMM Past Chairman (1968-1970).

# RAPID ASSESSMENT OF U-235 IN USED HIGH EFFICIENCY PARTICULATE AIR FILTERS

By W. F. Heine and
J. D. Moore

## INTRODUCTION

Current special nuclear material safeguards requirements preclude the disposal of high efficiency particulate air (HEPA) filters which have been used in air exhaust systems for areas in which enriched uranium is utilized until the amount of U-235 contained in the filter has been determined. To this end, a technique has been developed for evaluating U-235 contained in used HEPA filters by selectively measuring the emission rate of the 0.185 Mev (54 percent) photon from U-235.

Counting of the 0.185 Mev photon is performed with a NaI (Tl) planar gamma detector, driving a portable, battery-operated pulse rate meter with single-channel pulse height analyzer and pulse integrator capabilities.* Filters are placed in a fixture designed to assure consistent source-detector geometry, and subjected to an appropriate count on each face of the filter medium with the detector positioned at the center of the face at a distance of 2" from the surface of the medium. The U-235 contained in the filter is determined on the basis of the observed count rate on a filter face and the ratio of the count rates on the two faces.

## SOURCE DATA

The HEPA filters are open-face filters composed of a continuous sheet of cellulose-asbestos paper (the filter medium) which is pleated back and forth over corrugated aluminum separators which add strength to the filter core and form air passages between the folds. The filter core is sealed into a full-depth wood or metal frame by means of an adhesive, Reference 1. The outside dimensions of the filter frame are 24" x 24" x 12" deep. The dimensions of the filter core are 22" x 22" x 10" deep.

In attempting to establish a model for the source configuration, it became apparent that volume-distributed source models approximating the physical configuration of the filter, e.g., cylinder, sphere, etc., are not appropriate models. Initial evaluation of filters which had been removed from exhaust systems revealed that, although the filter loading was evenly distributed laterally across the filter, it was not evenly distributed as a function of depth in the filter. Measurements of the photon fluxes at the filter faces were in all cases characterized by one face with a higher flux than the other.

The model which was selected for the source configuration is an "equivalent plane circular source," set at a depth in the filter which is established by the ratio of the photon fluxes at the opposite faces of the filter. The depth of an equivalent plane source is plotted in Figure 1 as a function of the ratio of the fluxes at the filter faces. The ratios were determined by calculating the photon fluxes which would be present at the filter faces for an equivalent plane source set at various depths in the filter. Figure 2 describes for an equivalent plane source containing one gram of U-235 the flux at the filter face as a function of depth in the filter.

The method for evaluating the flux from a plane-circular source transmitting through an attenuating medium is described in Reference 2. The source is assumed to be a 25" diameter disc, which presents the same cross sectional area as does the square surface of the actual filter face. The flux (photons / $cm^2$-min) at 2" from the face of the filter core was evaluated incrementally for varying source depths as follows:

$$\phi = \left[\frac{BS_A}{2} \quad E_1(b_1) - E_1(b_1 \sec \theta)\right]$$

where;

$B$ = buildup factor (unity for 0.185 Mev photons)

$S_A$ = source strength of plane source (photons/$cm^2$-min)

$b_1$ = $\mu t$

$\mu$ = linear absorption coefficient of shield ($cm^{-1}$)

$t$ = shield thickness (cm)

$\theta$ = angle at point of measurement, described by the axis of the plane and a point on the perimeter of the plane.

$E_1(b_1)$ = function plotted in Reference 2

$$= \int_b^\infty \frac{e^{-1}}{t} \, dt$$

*Eberline Model SPA3, 2"x2" detector, PRM-5 portable ratemeter and PI-1 pulse integrator (descriptive only, other equipment may work equally well).

The self-attentuation in the filter was evaluated for 0.185 Mev photons by measuring the transmission through the filter of the photons from a known U-235 standard located successively at 25 positions on the face of the filter opposite a fixed, centally located detector. Since the attenuation varies with angle to the normal of transmission through the filter, due to the aluminum spacers which are oriented parallel to the normal, the effective linear absorption coefficient was derived from the average of the linear absorption coefficients calculated from the 25 transmission measurements. The average linear absorption coefficient for the 25 transmission measurements was 0.02 $in^{-1}$.

## COUNTING SYSTEM DATA

To determine the suitability of the counting system for detecting the 0.185 Mev photons from U-235, a series of measurements was made with variously enriched, 1-gram NBS *Certified* $U_3O_8$ *standards. This series of measurements* verified a linear relationship between detector response and U-235 enrichment.

The efficiency of the detector for the 0.185 Mev photons was determined by exposing it to known fluxes from the NBS standards and relating this flux to the observed count rate.

In order to reduce the background count rate and optimize the signal to noise ratio, the detector was shielded in such a manner as to reduce background contributions from directions other than the direction of the source. Optimum detector shielding configuration was determined by incrementally retracting a ⅛"-thick lead sheath covering the detector, and comparing the background count rate with the count rate from a U-235 standard positioned laterally from the detector face.

## APPLICATION

The detector, shielded to optimize the signal to noise ratio, is installed into the detector mount on the filter counting fixture, Figure 3, and adjusted so that the distance from the face of the detector to the surface of the filter medium is two inches. The 0.185 Mev photon flux at each face of the filter is evaluated, utilizing appropriate counting times. The net (background corrected) count rates measured at two inches from the faces of the filters are ratioed, and this ratio is used to determine from Figure 1 the depth in the filter of an equivalent plane source. On the basis of the depth of the equivalent plane source, the photon flux at two inches from a filter face per gram of U-235 can be taken from Figure 2. The amount of U-235 contained in the filter is determined as follows:

### REFERENCES


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Figure 1

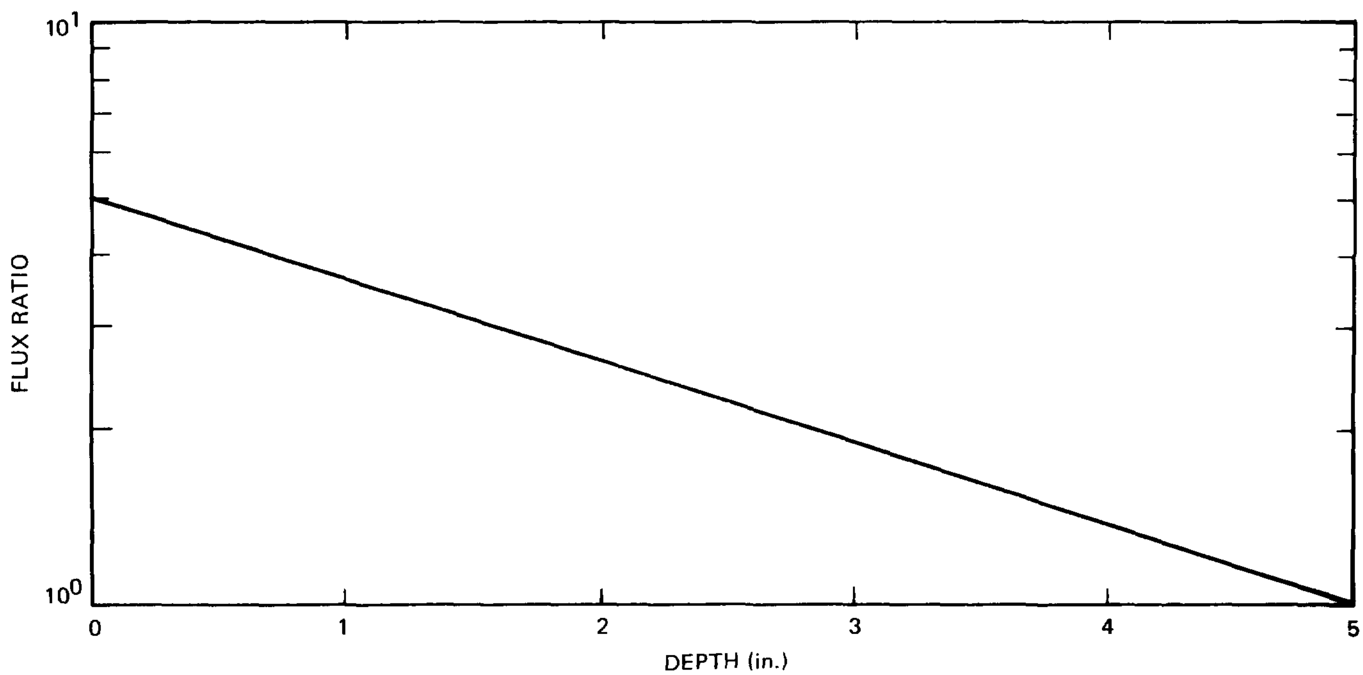



Figure 1. Depth in Filter Medium of an Equivalent Plane Source of U-235 as a Function of the Ratio of the Gamma Fluxes at the Faces of a HEPA Filter

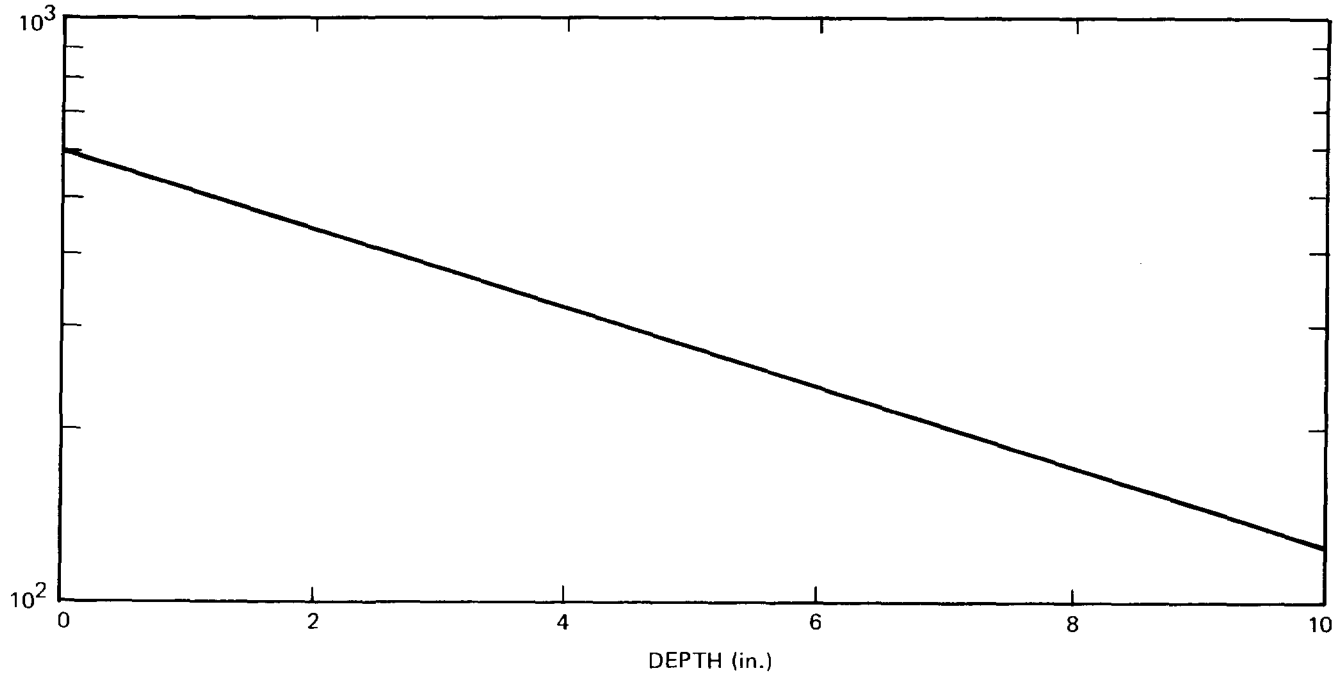
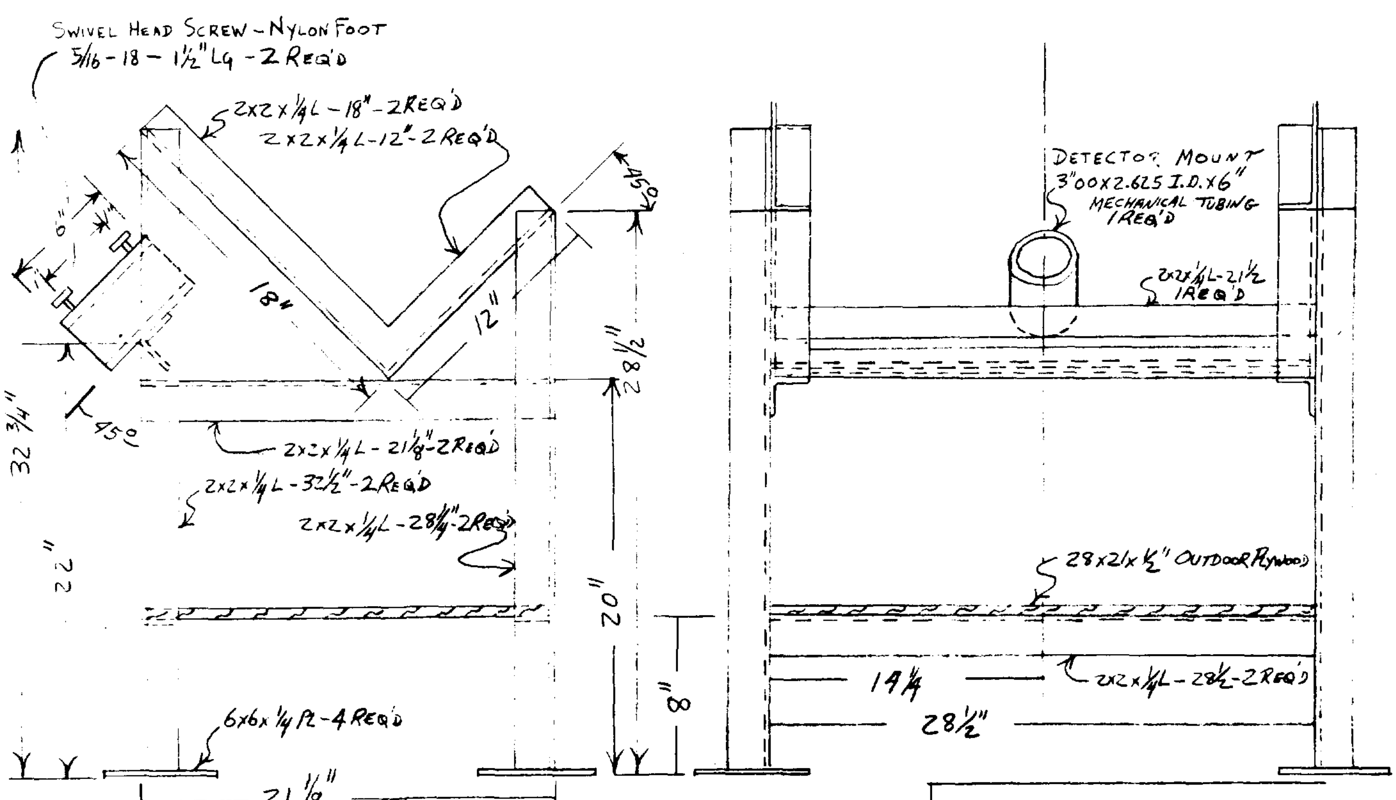



Figure 2. Flux at 2 in. from the Face of a HEPA Filter for an Equivalent Plane Source Containing One Gram of U-235 as a Function of Depth in the Filter Medium

Figure 2

Figure 3




HEPA Filter Counting Fixture

# CONTROL CHARTS FOR MUF'S

**By John L. Jaech**

## Introduction

When closing a material balance, the material unaccounted for (MUF) and its standard deviation are calculated. It is common practice to evaluate the MUF for significance by comparing it with the standard deviation. More specifically, if a positive MUF exceeds twice this calculated standard deviation, a quantity that is labeled the MUF limit of error, then the MUF is declared to be significant. That is to say, there is statistical evidence that the true MUF, the quantity estimated by the calculated MUF, is some value greater than zero.

Although the above test is a valid one and is an essential part of the MUF evaluation, there are some considerations that should enter into a more comprehensive evaluation. The calculated standard deviation of MUF normally reflects only the effects of statistical errors of measurement, i.e., those errors that are an inherent part of the measurement process. Mistakes or blunders in measuring, recording, and/or processing the measurement data do not affect this standard deviation although they do, of course, affect the value of the MUF. Further, such factors as hidden or unmeasured inventories and unmeasured losses also affect the size of MUF, but not its standard deviation as normally defined. It is only when perfection in operation is demanded that it is reasonable to conclude the MUF evaluation with the limit of error test.

How can these other factors be included in the evaluation? This can be accomplished by using past data from a facility judged to be "in-control" in the sense that unmeasured inventories and losses are minimized, as are human mistakes. These data can be used to estimate the parameters of the model that describe MUF behavior and, in turn, these estimates can be used to evaluate a given calculated MUF.

How this can be done is discussed in Chapter 7 of reference [1]. This article extends that discussion in several regards with the primary emphasis being an investigation of the conditions under which the special control chart presented in the reference represents an advantage over the somewhat simpler standard control chart.

## The Model

The mathematical model used in the reference just cited is reviewed briefly. Let

$X_j$ = observed or calculated MUF for material balance period j.

$M_j$ = true MUF for period j (true MUF includes the effects of mistakes, unmeasured losses, unmeasured inventories, etc.)

$\eta_j$ = random error of measurement for the ending inventory for period j.

$\delta$ = systematic error of measurement for the difference: (inputs-outputs). (Since $\delta$ has no subscript, it is assumed to be the same for all periods.)

$\varepsilon_j$ = random error of measurement for (inputs-outputs) for period j.

Then, $\chi_j$ can be written,

$$\chi_j = M_j + (\eta_j - \eta_{j-1}) + \delta + \varepsilon_j \qquad (1)$$

An equilibrium environment is assumed. In terms of the parameters, this means that $\eta_j$ and $\varepsilon_j$ are randomly sampled from (normal) populations having zero means and variances $\sigma^2{}_\eta$ and $\sigma^2{}_\varepsilon$, respectively. Also, $\delta$ is assumed to be randomly sampled from a (normal) population with zero mean and variance $\sigma^2{}_\delta$, while $M_j$ comes from a (normal) population with a mean of M and a variance $\sigma^2{}_M$. Finally, to account for the facts that mistakes made in one material balance period are often found and corrected in the ensuing period, and unmeasured inventory items for one period often become part of the measured inventory (or outputs) in the next period, assume that $M_j$ and $M_{j+1}$ are correlated with the covariance denoted by $\sigma_{M_j,M_{j+1}}$. This covariance is logically a negative quantity.

In the common MUF evaluation made with regards to the limit of error, it is pointed out that the limit of error is related to the parameters of the above model by the relationship:

$$LE = 2\sqrt{2\sigma^2{}_\eta + \sigma^2{}_\delta + \sigma^2{}_\varepsilon} \qquad (2)$$

In practice, the variances in (2) are evaluated separately for each material balance period. The model assumes that the LE given by equation (2) is constant over the equilibrium period of operation under study. Note also that the LE in equation (2) assumes that $\sigma^2{}_M = 0$.

## Control Charts

Two kinds of control charts are considered. The standard control chart (SCC) plots the observed MUF, $\chi_j$, and has limits of the form

$$M \pm k\sigma_1 \qquad (3)$$

where

$$\sigma_1 = \sqrt{\sigma^2{}_M + 2\sigma^2{}_\eta + \sigma^2{}_\delta + \sigma^2{}_\varepsilon} \qquad (4)$$

These limits are equivalent to the common LE test if k = 2, M = 0, and $\sigma^2{}_M = 0$.

The second control chart, which we will call a difference control chart (DCC) in this paper makes use of the fact that successive calculated MUF's are correlated. The quantity plotted is

$$\begin{aligned} \chi'_j &= \chi_j - \rho(\chi_{j-1} - M) - M \\ &= \chi_j - \rho\chi_{j-1} + M(\rho-1) \qquad (5) \end{aligned}$$

where

$$\rho = \frac{\sigma_{M_j,M_{j+1}} - \sigma^2{}_\eta + \sigma^2{}_\delta}{\sigma^2{}_M + 2\sigma^2{}_\eta + \sigma^2{}_\delta + \sigma^2{}_\varepsilon} \qquad (6)$$

The control limits on $\chi_j$ are of the form

$$0 \pm k\sigma_2 \qquad (7)$$

where

$$\begin{aligned} \sigma_2{}^2 = {} & (1 + \rho^2)\ \sigma^2{}_M - 2\rho\sigma_{M_j,M_{j+1}} \\ & + 2(1 + \rho + \rho^2)\sigma^2{}_\eta \\ & + (1 - \rho)^2\sigma^2{}_\delta + (1 + \rho^2)\sigma^2{}_\varepsilon \qquad (8) \end{aligned}$$

This is the form of $\sigma^2{}_2$ given in reference [1]. An equivalent expression which is more suitable for present purposes is

$$\begin{aligned} \sigma_2{}^2 &= \sigma_\chi{}^2(1 - \rho^2) \\ &= (\sigma_M{}^2 + 2\sigma_\eta{}^2 + \sigma_\delta{}^2 + \sigma_\varepsilon{}^2) \\ & \quad (1 - \rho^2) \qquad (9) \end{aligned}$$

Use of Data to Estimate Parameters

There are several ways in which past MUF data can be used to estimate the parameters of the model, as discussed in reference [1]. Since $\sigma^2_\eta$ and $\sigma^2_\varepsilon$ are calculated from other considerations, the most logical approach is to assign average values to $\sigma_\eta^2$ and $\sigma_\varepsilon^2$ and then estimate $\sigma_M^2$ and $\sigma_{M_j,M_{j+1}}$ from the data. This is done be calculating the variance, $s_\chi^2$ of the observed MUF values, and the covariance between successive MUF's, denoted by $s_{j,j+1}$.

$$s_\chi^2 = \frac{\sum_{j=1}^{n} \chi_j^2 - \left(\sum_{j=1}^{n} \chi_j\right)^2/n}{(n-1)} \tag{10}$$

$$s_{j,j+1} = \sum_{j=1}^{n-1} \chi_j\chi_{j+1}/(n-1) - \left(\sum_{j=1}^{n} \chi_j\right)^2/n^2 \tag{11}$$

Then, $\sigma_M^2$ and $\sigma_{M_j,M_{j+1}}$ are estimated by

$$\hat{\sigma}_M^2 = \frac{2n(s_{j,j+1} - s_\chi^2) + (n^2+2)s_\chi^2}{n(n-2)} - 2\sigma_\eta^2 - \sigma_\varepsilon^2 \tag{12}$$

$$\hat{\sigma}_{M_{j,j+1}} = \frac{s_\chi^2 + ns_{j,j+1}}{(n-2)} + \sigma_\eta^2 \tag{13}$$

With these estimates, and with values assigned to $\sigma_\eta^2$, $\sigma_\varepsilon^2$, and $\sigma_\delta^2$, the control charts given by (3) and (7) can be constructed, where $\sigma_1$ and $\sigma_2$ are defined by (4) and (8) or (9), respectively, with $\rho$ given in (6). The other parameter needed to construct these charts is M, the average true MUF. This is estimated by $\bar{\chi}$, the average observed MUF.

Before comparing the DCC and the SCC, it is pointed out that if we simply wish to use a DCC without trying to obtain separate estimates of the variance components, then there is no need to estimate $\sigma_M^2$ and $\sigma_{M_{j,j+1}}$ from (12) and (13).

Rather, with a value assigned to $\sigma_\delta^2$, it is easily seen from equations (6), (9), and (12) that the variance used in the construction of the DCC is

$$\sigma_2^2 = \frac{(A+\sigma_\delta^2)^2 - (B+\sigma_\delta^2)^2}{(A+\sigma_\delta^2)} \tag{14}$$

where

$$A = \frac{2n(s_{j,j+1} - s_\chi^2) + (n^2+2)s_\chi^2}{n(n-2)} \tag{15}$$

and

$$B = \frac{s_\chi^2 + ns_{j,j+1}}{(n-2)} \tag{16}$$

Comparison of Control Charts

The SCC of (3) is easier to construct and implement than is the DCC. What then is to be gained by using the more complicated DCC? The first step in answering this question is to compare the variance, $\sigma_1^2$ and $\sigma_2^2$, where $\sigma_1^2$ is the variance of $\chi_j$ used with the SCC, and $\sigma_2^2$ is the variance of $\chi_j'$ used with the DCC. This is easily accomplished by noting from (4) and (9) that

$$\frac{\sigma_2^2}{\sigma_1^2} = 1 - \rho^2$$

with $\rho$ given by (6).

Note immediately that the DCC is always at least as good as the SCC in the sense that it has tighter limits because $\sigma_2^2$ is never greater than $\sigma_1^2$, as follows by (17) since $\rho^2 \leq 1$. The question that remains is how much better the DCC is as compared with the SCC. This is answered by evaluating $P = \sigma_2^2/\sigma_1^2$ as a function of the parameters which affect $\rho$. In particular, from (6) and (17), write

$$P = 1 - \left(\frac{kr_1 + r_2 - 1}{2 + r_1 + r_2 + r_3}\right)^2 \tag{18}$$

where

$$k = \sigma_{M_{j,j+1}} / \sigma_M^2$$

$$r_1 = \sigma_M^2/\sigma_\eta^2$$

$$r_2 = \sigma_\delta^2/\sigma_\eta^2 \qquad (19)$$

$$r_3 = \sigma_\varepsilon^2/\sigma_\eta^2$$

The relationship between P and the parameters k, $r_1$, $r_2$, and $r_3$ were investigated in a series of calculations, and the results are plotted in Figures (1) - (9). These indicate the regions in which $P = \sigma_2^2/\sigma_1^2$ is "small", which correspond to those sets of conditions in which it is attractive to use the DCC rather than the SCC.

Comparison of Test Powers

A control chart is equivalent to a statistical test of an hypothesis. Therefore, the comparison in the previous section has more meaning if it is done in terms of test powers. That is, what is the implication of a given value for P in terms of the ability of a test to produce a significant result, or an out-of-control point in control chart terminology?

To answer this question, Figure (10) was constructed. The use of this figure is best shown by an example. (This example assumes that k = 3, i.e., that $3\sigma$ control limits are used). Suppose that the true MUF is 2.5 standard deviations, ($\sigma_1$), larger than the hypothesized MUF, denoted by $M_0$ in this figure. Then, with reference to the curve labeled "$H_A$:$M_0$ + 2.5 sigma," the probability is 0.31 that an observed MUF will lead to an out-of-control point with the SCC. If the DCC produces a P value of 0.70, i.e., if the variance for the DCC is 70% of that for the SCC, then this probability increases to 0.49.

This figure indicates, as is intuitively obvious, that significant improvements in the use of the DCC require that P be reasonably small, and even here, these improvements exist only in the borderline regions. That is to say, if the true MUF is either very small (relative to $M_0$) or very large, there is little to gain by using the DCC. In the first event, it won't be detected anyway while in the latter event, the SCC will detect the shift with high probability, and recourse need not be made to the more powerful DCC.

Example

The following monthly MUF data in grams plutonium are reported by Nilson [2].

Table I

Monthly MUF Data (gr Pu)

| Month | MUF | Month | MUF |
|---|---|---|---|
| 1 | - 1 | 10 | 22 |
| 2 | 22 | 11 | 15 |
| 3 | 8 | 12 | - 2 |
| 4 | 2 | 13 | 11 |
| 5 | - 7 | 14 | 7 |
| 6 | 0 | 15 | 22 |
| 7 | - 4 | 16 | 0 |
| 8 | 51 | 17 | 32 |
| 9 | -17 | | |

The DCC control chart is constructed, and is compared with the SCC. The key statistics are

$$n = 17 \qquad \bar{\chi} = 9.5 \qquad s_{j,j+1} = -138.44$$

$$\Sigma\chi = 161 \qquad s_\chi^2 = 273.39$$

Let $\sigma_\eta^2$, $\sigma_\delta^2$, and $\sigma_\varepsilon^2$ be assigned the following values, where the data are based on LE calculations performed monthly, and represent average values for these parameters.

$$\sigma_\eta^2 = 100 \qquad \sigma_\delta^2 = 10 \qquad \sigma_\varepsilon^2 = 10$$

Then, from equations (12), (13), (6), and (9),

$$\hat{\sigma}_M^2 = \frac{34(-138.44 - 273.39) + 291(273.39)}{255}$$

$$- 200 - 10$$

$$= 47.08 \text{ g}^2 \text{ Pu}$$

$$\hat{\sigma}_{M_j,M_{j+1}} = \frac{273.39 + 17(-138.44)}{15} + 100$$

$$= -38.67 \text{ g}^2 \text{ Pu}$$

$$P = \frac{-38.67 - 100 + 10}{47.08 + 200 + 10 + 10} = -0.482$$

$$\sigma_2 = \sqrt{(267.08)(1 - .2323)} = 14.3 \text{ g Pu}$$

This is the standard deviation to be used in the construction of the DCC. By way of comparison, $\sigma_1$ in the SCC is, by equation (4)

$$\sigma_1 = \sqrt{267.08} = 16.3 \text{ g Pu}$$

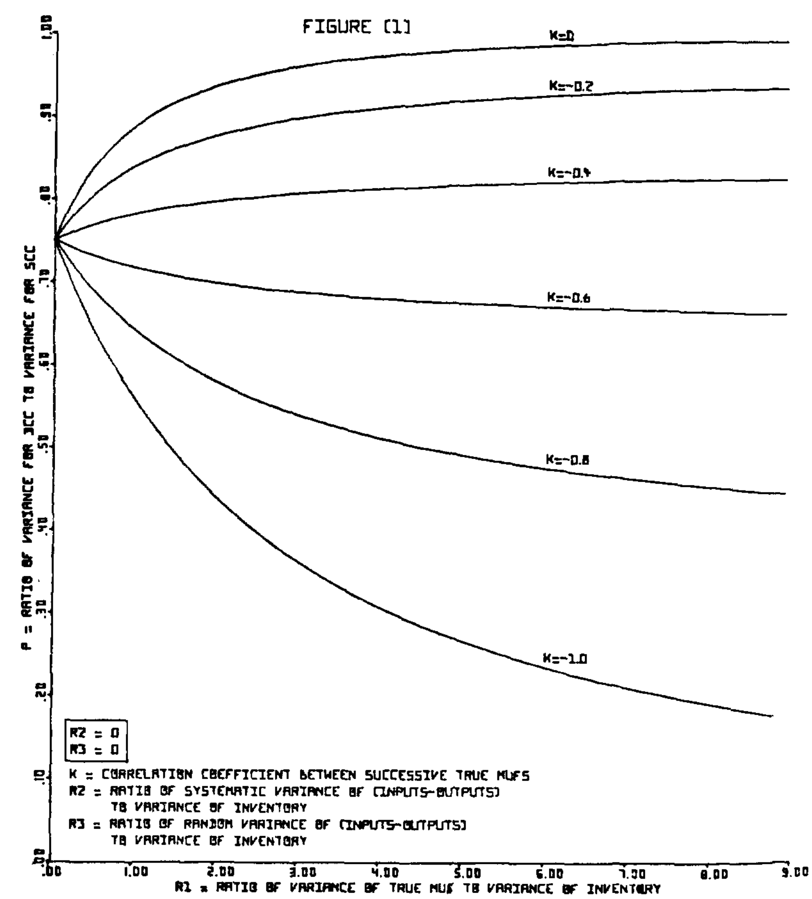
In applying figure (10), $P = (14.3/16.3)^2 = 0.77$. Thus, if a given true MUF should be 3.0 $\sigma_1$ or 48.9 g Pu greater than the hypothesized or tolerable MUF, there is a probability of 0.50 of detecting this with the SCC, and the probability is 0.66 with the DCC.

The SCC and the DCC are both constructed for these data, and are given as figure (11). In each case, the inner control limits are at the two sigma level, and the outer lines represent three sigma control limits.

## References


1. J. L. Jaech, Statistical Methods in Nuclear Material Control, TID-26298, September, 1973.

2. R. Nilson, "Formulation and Verification of Materials Balance Pro Forma for a Plutonium Fuels Fabrication Facility," INMM 14th Annual Meeting, June, 1973.

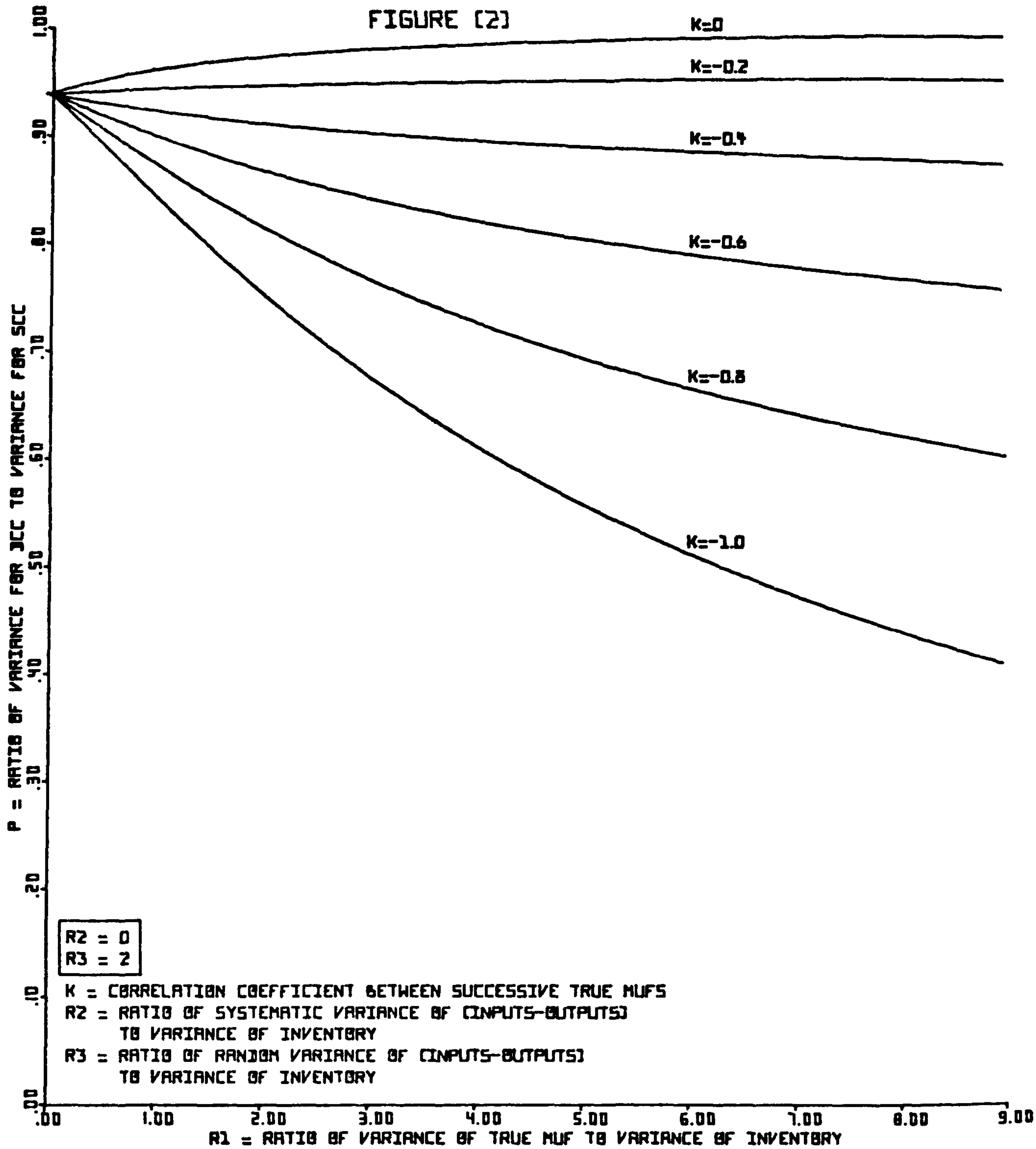


FIGURE [2]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
R2 = 0
R3 = 2
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY

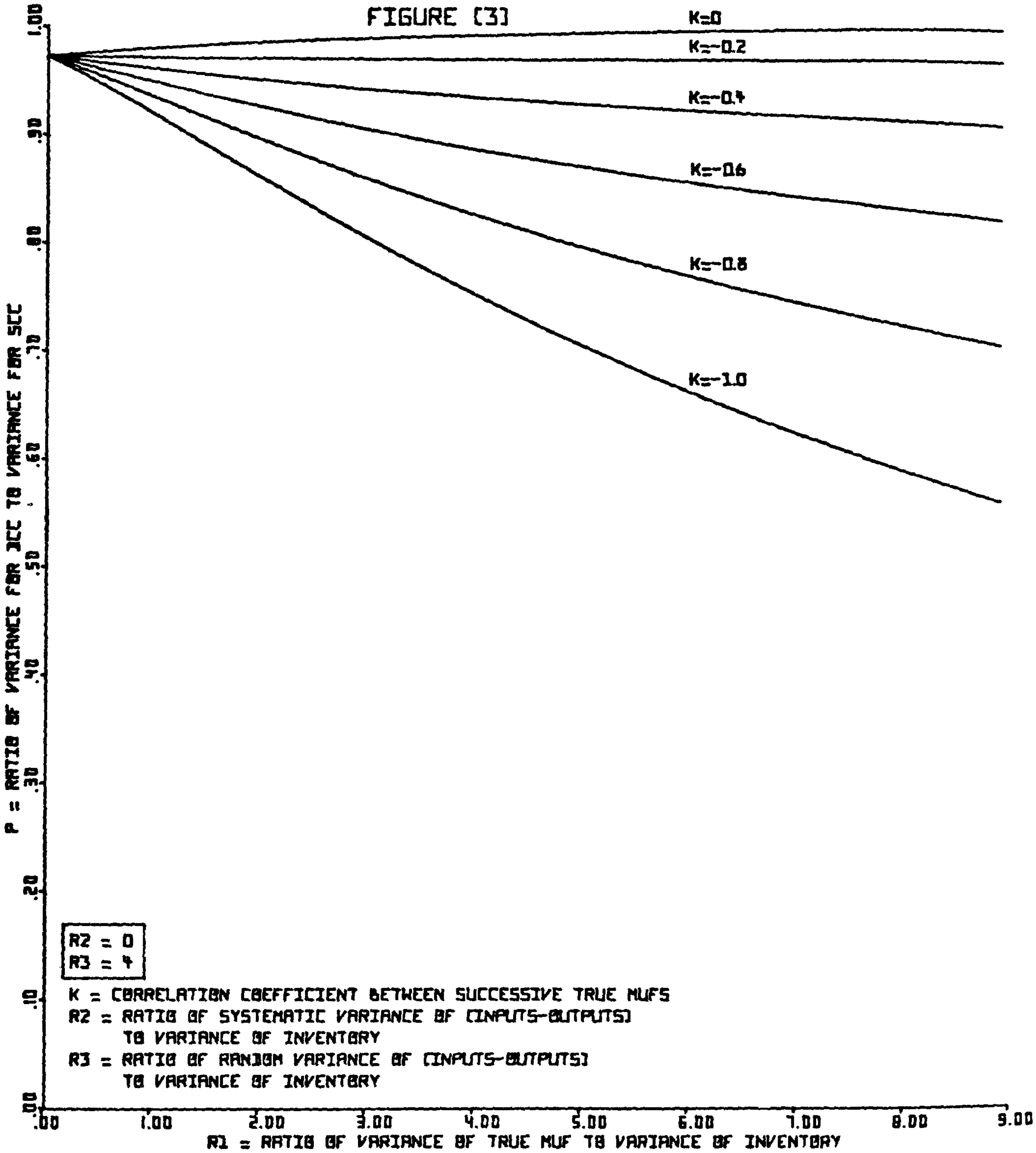


FIGURE [3]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
R2 = 0
R3 = 4
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY

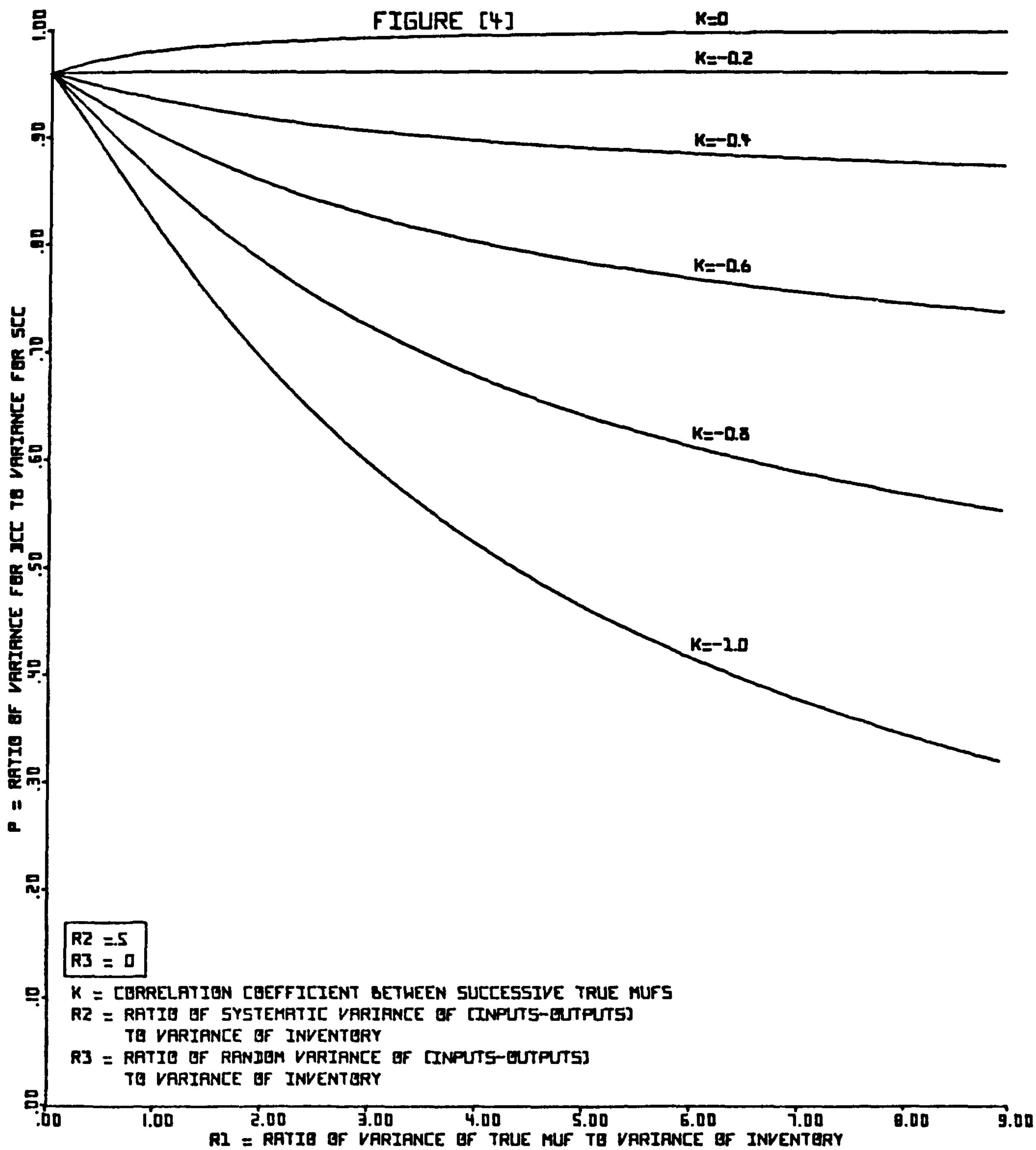


FIGURE [4]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR 3CC TO VARIANCE FOR SCC
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY
R2 =.5
R3 = 0
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00

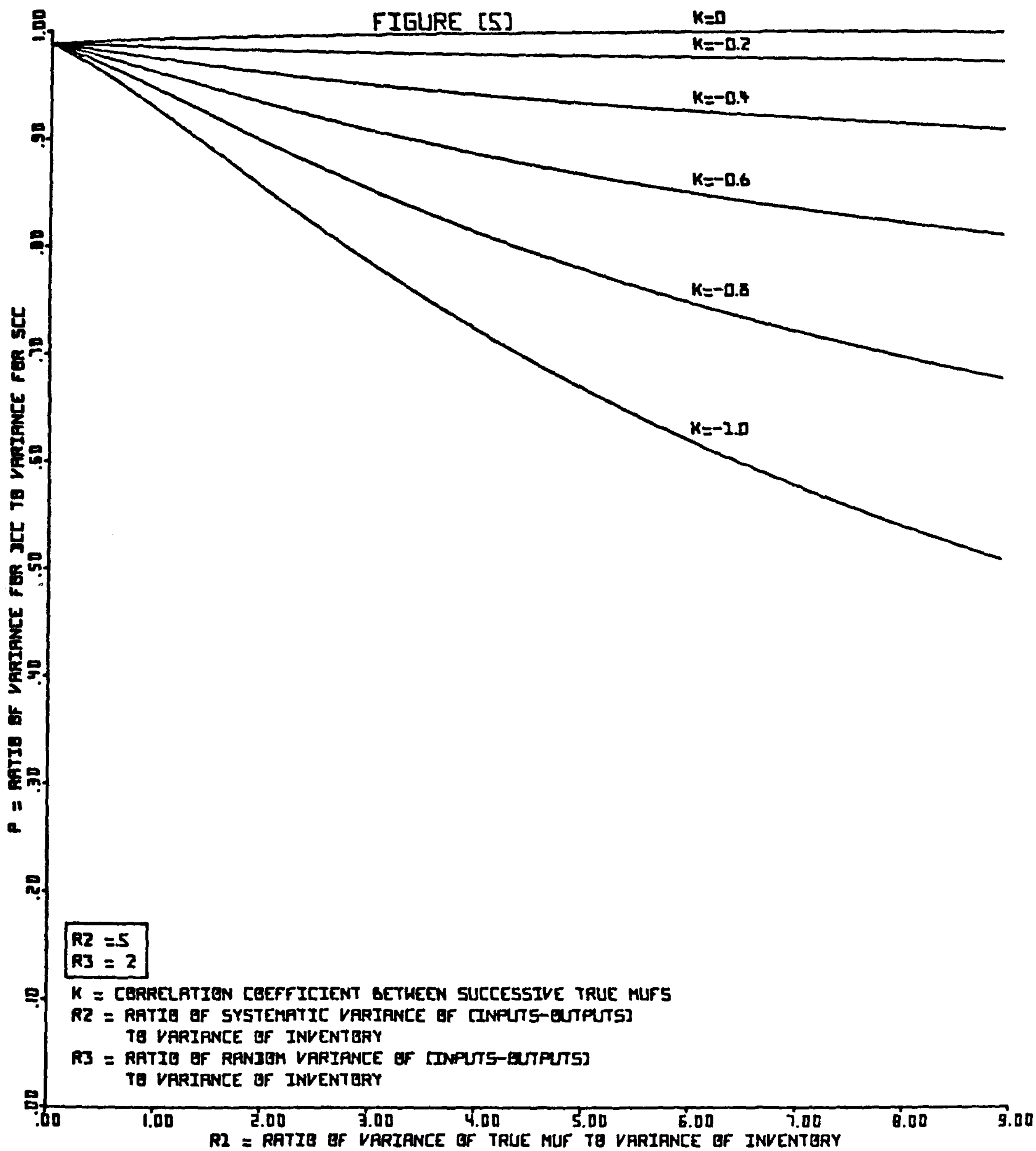


FIGURE [5]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR ICC TO VARIANCE FOR SCC
R2 = .5
R3 = 2
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY

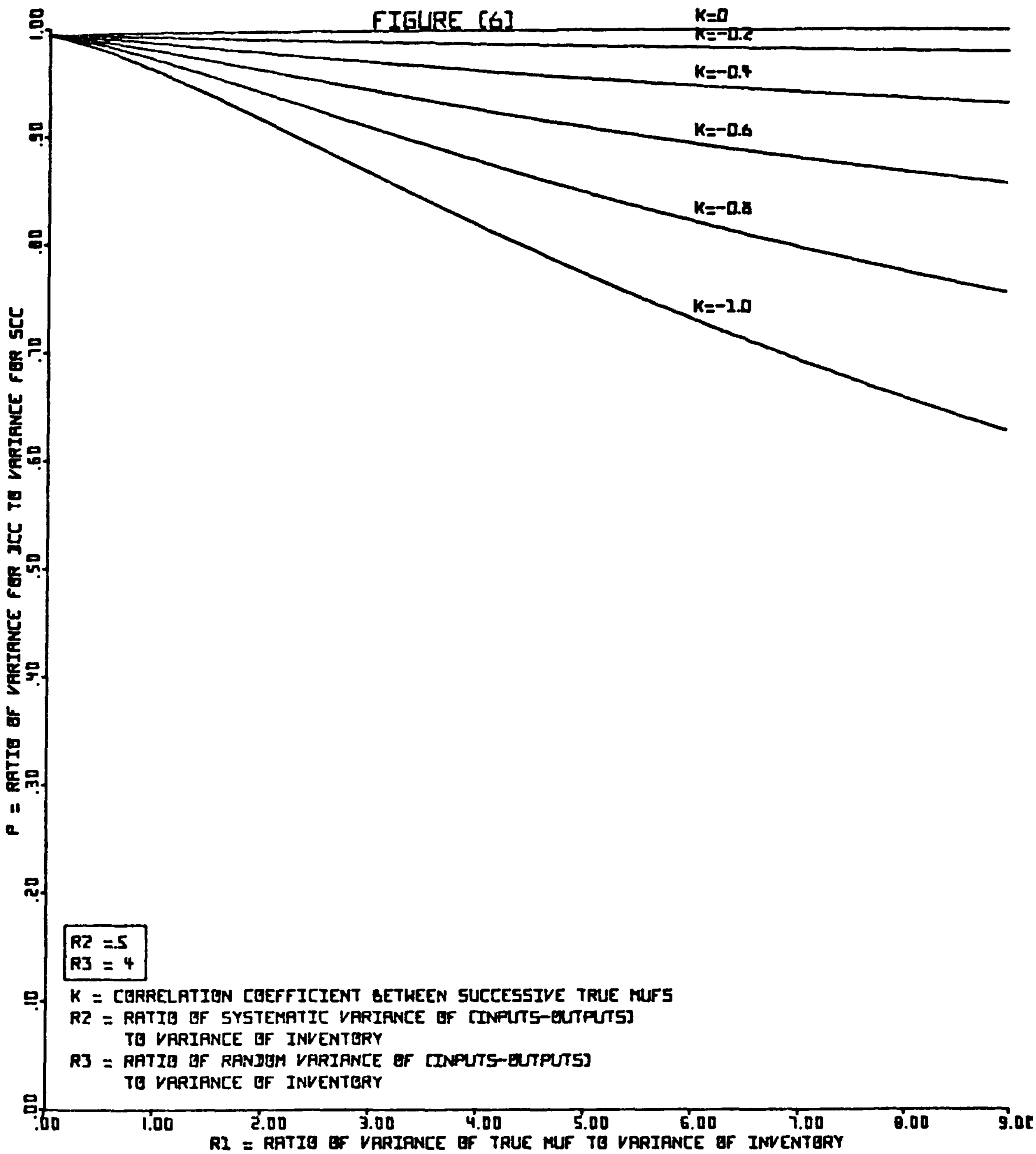


FIGURE [6]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY
R2 =.5
R3 = 4
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00

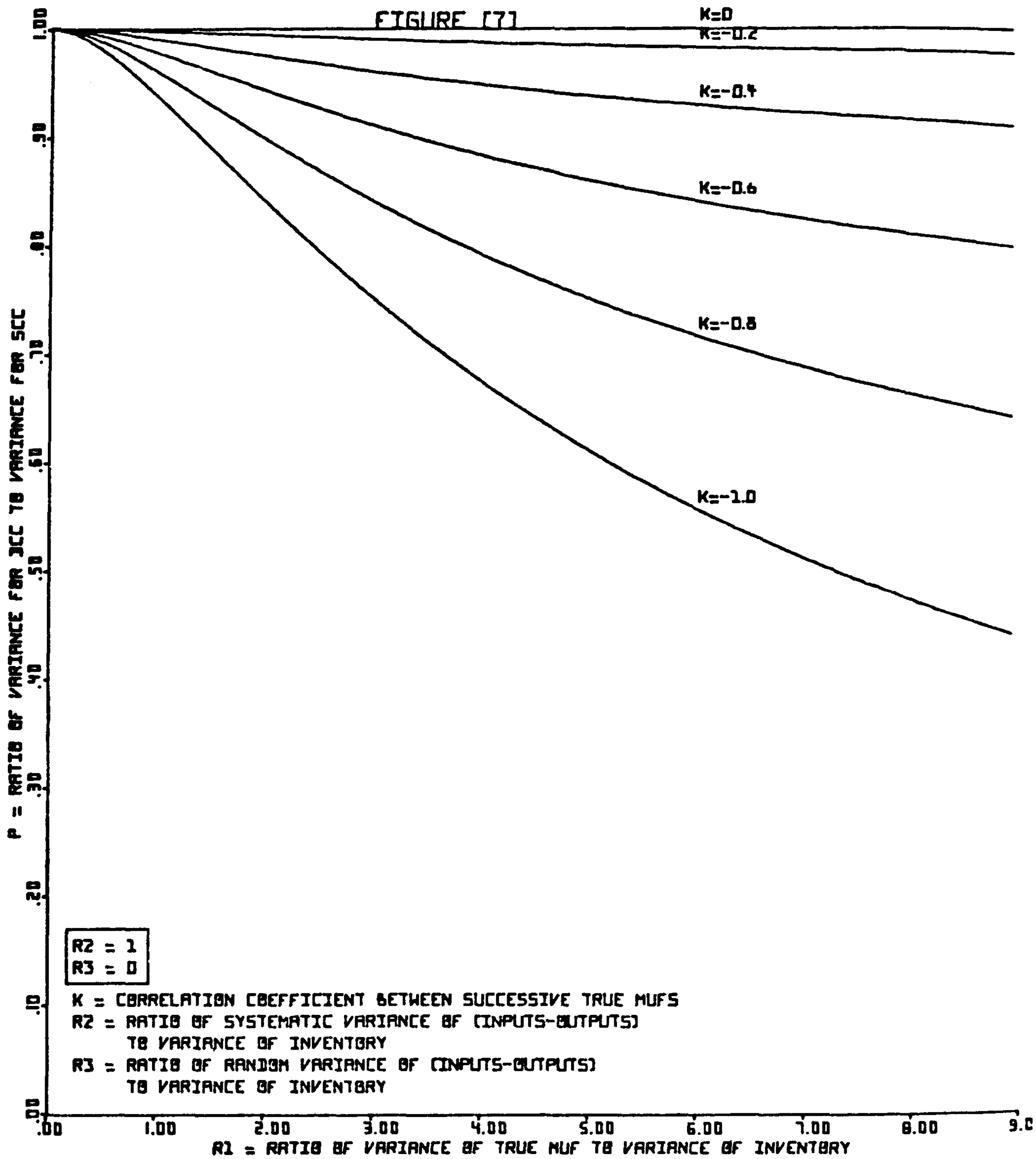


FIGURE [7]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
R2 = 1
R3 = 0
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF (INPUTS-OUTPUTS) TO VARIANCE OF INVENTORY
.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY

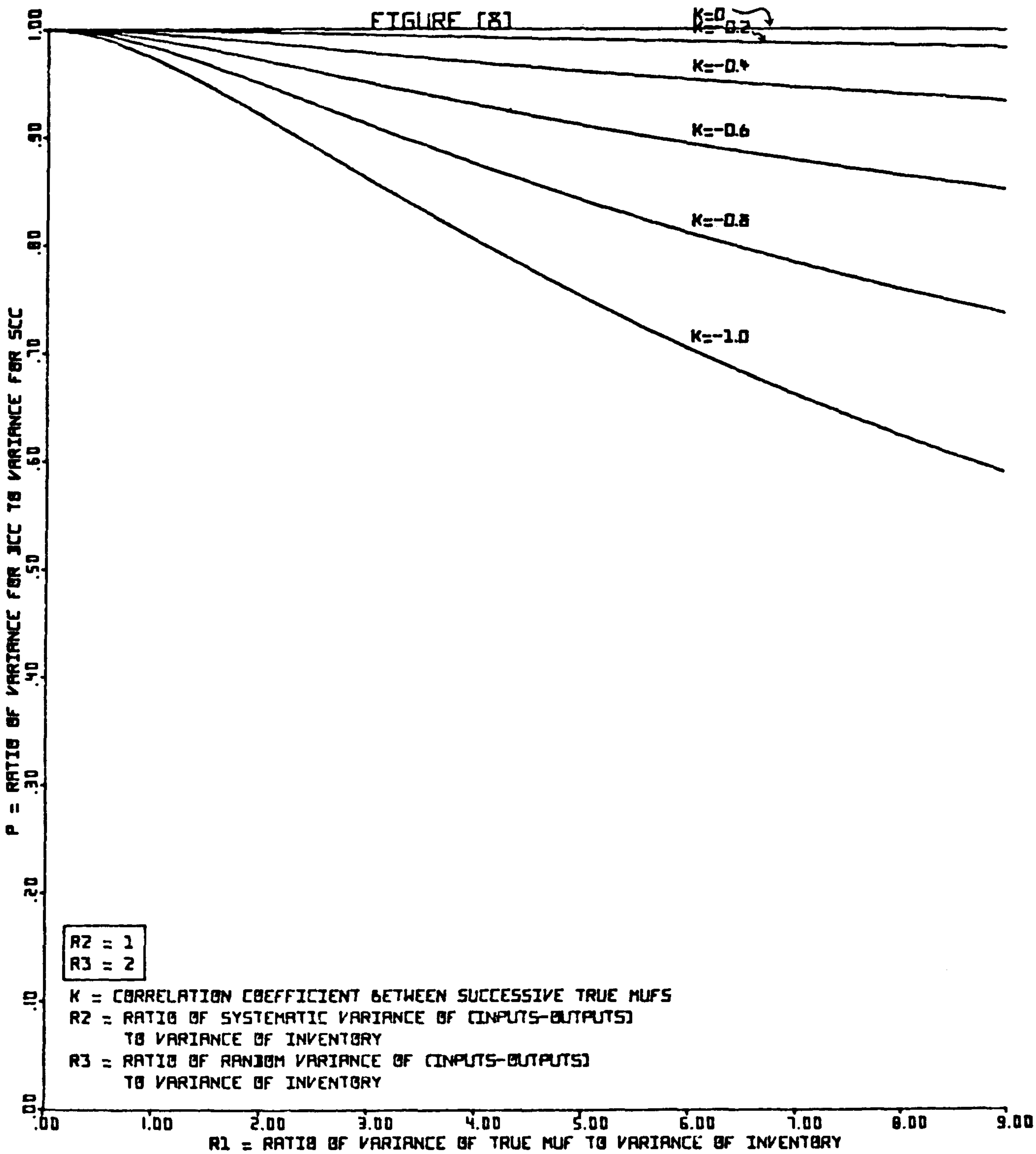


FIGURE [8]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
R2 = 1
R3 = 2
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY
.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00

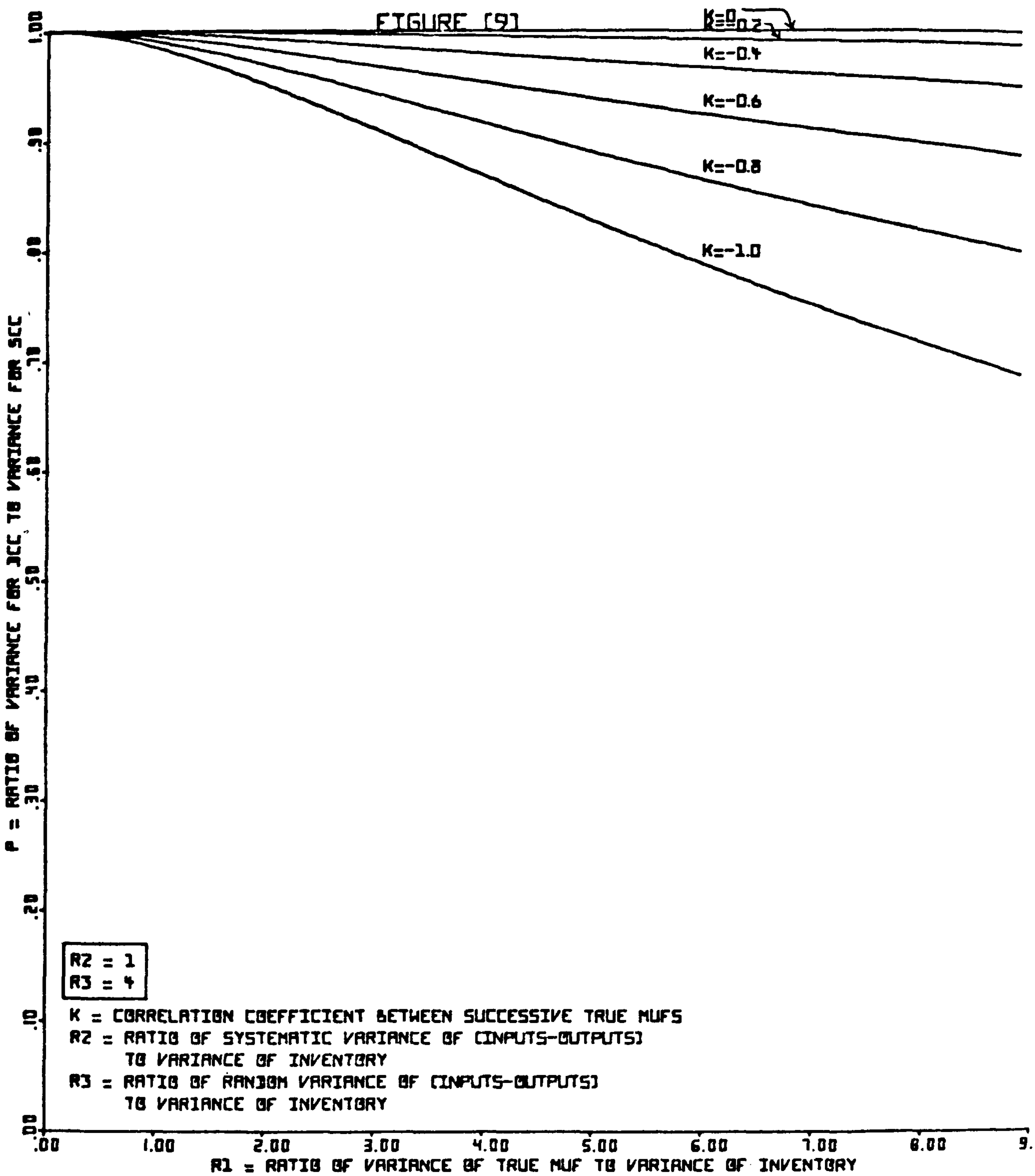


FIGURE [9]
K=0
K=-0.2
K=-0.4
K=-0.6
K=-0.8
K=-1.0
P = RATIO OF VARIANCE FOR JCC TO VARIANCE FOR SCC
.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
R2 = 1
R3 = 4
K = CORRELATION COEFFICIENT BETWEEN SUCCESSIVE TRUE MUFS
R2 = RATIO OF SYSTEMATIC VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
R3 = RATIO OF RANDOM VARIANCE OF [INPUTS-OUTPUTS] TO VARIANCE OF INVENTORY
.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
R1 = RATIO OF VARIANCE OF TRUE MUF TO VARIANCE OF INVENTORY