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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

May 27 - June 6, 1980

PROCEEDINGS

MASTER

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in cooperation
with International Atomic Energy Agency
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Los Alamos, New Mexico

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

PROCEEDINGS

Lecture Text and Reference Material
Sessions 1—17

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B. PONTES, IAEA Scientific Advisor
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Bishop's Lodge
Santa Fe, New Mexico

May 27 - June 6, 1980

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

FOREWORD

This first International Training Course on Nuclear Materials Accountability for Safeguards Purposes was developed to provide practical training in the design, implementation, and operation of a national system of nuclear material accountability and control to meet national safeguards objectives and the international objective of facilitating effective IAEA safeguards. The course was sponsored by the US Department of Energy in cooperation with the International Atomic Energy Agency, and was conducted at Santa Fe, NM by the staff of the Los Alamos Scientific Laboratory of the University of California.

A total of some 70 participants (including course attendees and lecturers) from 23 nations took part. Nations represented included Brazil, Canada, Chile, Denmark, Egypt, the Federal Republic of Germany, the German Democratic Republic, Greece, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Kenya, Korea, Pakistan, Philippines, Portugal, Taiwan, Turkey, and the United States. Participants also came from the sponsoring organization, the IAEA in Vienna, and the EURATOM organization of the Commission of the European Communities in Luxembourg.

As attested by the Schedule of Sessions and Invited Lecturers shown in the Table of Contents, a truly outstanding course instructional staff was assembled from among leading safeguards and materials management experts in national laboratories, government, and private industry, from both the United States and abroad.

The course emphasized safeguards requirements, necessary resources, and implementation as applied to power reactor/

spent-fuel storage facilities and research reactor facilities. The first week covered the general principles and practice of safeguards - its evolution, basic structure, and current practice. Topics included IAEA and EURATOM safeguards, state system requirements, materials accountability and control, and practical applications of safeguards at several different types of nuclear facilities.

The second week of the course involved more detail on the instrumentation and technology required to implement modern safeguards systems. The lecture material was correlated with, and supported by, tours and demonstrations (at the Los Alamos Safeguards R&D Laboratories) of state-of-the-art instrumentation and equipment. Detailed descriptions were given of current safeguards practice and actual operating experience in existing power-reactor and research-reactor facilities. The principles and practical application of safeguards system design were then presented and the resources required for their implementation were surveyed. The second week of the course culminated in the "product" of the course -- the workshop in facility safeguards systems design -- in which each course attendee participated as a member of a designated design subgroup. The course concluded with individual design subgroup reports and an evaluation of the workshop results, as well as an overall evaluation of the entire course.

The sharing of diverse viewpoints and approaches to safeguards issues and problems taken by different lecturers underscores the great need for consensus, international cooperation, and standardization in the implementation of equitable, effective safeguards on both the national and international level. It was further noted that this need is an important underlying factor in the basic thrust and overall purpose of the training course pursuant to the Nuclear Non-Proliferation Act of 1978 (NNPA).

At the concluding session of the course, it was emphasized that each of the countries represented has its own characteristic set of energy problems with correspondingly unique national concerns and approaches to the difficult issues posed by nuclear energy. Many participants expressed the belief that the overall thrust of the course, including the lectures, the workshop, and the opportunity for direct interactions with safeguards colleagues from around the world, would contribute to better communication and understanding, and thereby to the implementation of more effective safeguards, not only in the different countries they represented, but throughout the worldwide nuclear community.

These Proceedings of the 1980 "International Training Course on Nuclear Materials Accountability for Safeguards Purposes" include the full text of all course presentations; copies are available from the Department of Energy, Office of Safeguards and Security, and the Los Alamos Scientific Laboratory. All lectures were also videotaped for review by participants during the course and for use as training aids in the future.

G. Robert Keepin
NNPA Course Director
Los Alamos, NM
1 October 1980

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

ABSTRACT

The two volumes of this report incorporate all lectures and presentations at the International Training Course on Nuclear Materials Accountability and Control for Safeguards Purposes, held May 27-June 6, 1980 at the Bishop's Lodge near Santa Fe, New Mexico. The course, authorized by the US Nuclear Non-Proliferation Act and sponsored by the US Department of Energy in cooperation with the International Atomic Energy Agency, was developed to provide practical training in the design, implementation, and operation of a National system of nuclear materials accountability and control that satisfies both National and IAEA International safeguards objectives.

Volume I, covering the first week of the course, presents the background, requirements, and general features of material accounting and control in modern safeguard systems. Volume II, covering the second week of the course, provides more detailed information on measurement methods and instruments, practical experience at power reactor and research reactor facilities, and examples of operating state systems of accountability and control.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

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SESSION #16: INSPECTION OF REACTOR AND SPENT FUEL STORAGE FACILITIES - Les Thorne

VOLUME II

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY AND CONTROL FOR SAFEGUARDS PURPOSES

MONDAY, MAY 26, 1980
1600-1800 - REGISTRATION
1700-1900 - SOCIAL HOUR

TIME	TUESDAY 27 MAY	WEDNESDAY 28 MAY	THURSDAY 29 MAY	FRIDAY 30 MAY		MONDAY 2 JUNE	TUESDAY 3 JUNE	WEDNESDAY 4 JUNE	THURSDAY 5 JUNE	FRIDAY 6 JUNE
0700	BREAKFAST	BREAKFAST	BREAKFAST	MEET AT STABLE TRAIL RIDE AND BREAKFAST (REGULAR BREAKFAST OPTIONAL)	OPTIONAL TOUR OF NORTHERN NM — SATURDAY, 31 MAY 1980 FREE TIME — SUNDAY, 1 JUNE 1980	BREAKFAST	BREAKFAST	BREAKFAST	BREAKFAST	BREAKFAST
0730	REGISTRATION									
0800							DEPART BISHOP'S LODGE-TRAVEL TO LOS ALAMOS			
0830		6. DOMESTIC ACCOUNTABILITY AND CONTROL FEATURES (LUMB)	9. INTRODUCTION TO NUCLEAR FUEL CYCLES (KNIEF)			18. ELEMENTS OF CHEMICAL AND BULK MEASURE-MENT TECHNOLOGY (BINGHAM)		23. AN LWR POWER REACTOR FACILITY (REED)	30. IMPLEMENTATION OF THE FACILITY SAFEGUARDS SYSTEM (POWERS)	31. WORKSHOP CONTINUED
0900	1. WELCOME (KERR, WEISZ, von BAECKMANN)						22. TOUR OF LASL SAFEGUARDS LABORATORIES			
0930				14. NUCLEAR MATERIALS ACCOUNTING AND CONTROL IN POWER REACTORS (FOLEY, HIGINBOTHAM)				BREAK		
0945	2. INTRODUCTION TO TRAINING COURSE (WEISZ, von BAECKMANN, KEEPIN)							24. A CANDU POWER REACTOR FACILITY (SINDEN)		
1000		BREAK	BREAK			BREAK	BREAK		BREAK	BREAK
1030	BREAK	7. EURATOM SAFEGUARDS (MIRANDA)	10. ELEMENTS OF NUCLEAR MATERIAL ACCOUNTING (LUMB)			19. ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY (SMITH, CANADA)	22. TOUR CONTINUED		31. WORKSHOP IN FACILITY SAFEGUARDS SYSTEM DESIGN	32. PLENARY SESSION AND WRAP-UP OF SAFEGUARDS SYSTEM DESIGN WORKSHOP
1045				15. SAFEGUARDING OF NUCLEAR RESEARCH FACILITIES (JOHNSON)				BREAK		
1100	3. HISTORICAL AND POLITICAL FRAMEWORK OF SAFEGUARDS (TAPE)							25. A RESEARCH REACTOR FACILITY (TINGEY)		
1130										
1200	LUNCH AND FREE TIME	LUNCH AND FREE TIME	LUNCH AND FREE TIME	LUNCH AND FREE TIME		LUNCH AND FREE TIME		LUNCH AND FREE TIME	LUNCH AND FREE TIME	LUNCH AND FREE TIME
1230							BOX LUNCH AT BANDELIER			
1330								26. SAFEGUARDS SYSTEM DESIGN AND APPLICATION (SHIPLEY, COBB, HAKKILA, OLSON)		
1400		8. IAEA INTERNATIONAL SAFEGUARDS (BUECHLER)	11. NUCLEAR MATERIAL CONTROL (OLSON)	16. INSPECTION OF REACTOR AND SPENT FUEL STORAGE FACILITIES (THORNE)						33. GENERAL DISCUSSION, COMMENTS, AND CONCLUSIONS
1430								BREAK		
1445								27. DESIGN FEATURES RELEVANT TO IMPROVED SAFEGUARDS IMPLEMENTATION (GUPTA)		
1500		BREAK							31. WORKSHOP CONTINUED	
1515		IAEA INTERNATIONAL SAFEGUARDS (THORNE)								
1530			BREAK	BREAK						BREAK
1545								BREAK		
1600	4. DESCRIPTION OF A STATE SYSTEM AND ITS REQUIRE-MENTS (PARTLOW)		12. SURVEY OF STATISTICAL METHODS IN NUCLEAR MATERIAL ACCOUNTING AND CONTROL (JAECH)	17. PREWORKSHOP SESSION AND REVIEW (SHIPLEY; IAEA AND LASL STAFF)		20. NATIONAL SYSTEM OF MEASUREMENT STANDARDS (YOLKEN)	TOUR OF LASL SCIENCE MUSEUM	28. EXAMPLE OF AN OPERATING STATE SYSTEM – GDR (ROEHNSCH)		DOE WRAP UP OF COURSE
1615		BREAK								
1630		IAEA INTERNATIONAL SAFEGUARDS (HOUGH)								
1700										NO-HOST SOCIAL HOUR
1715							RECEPTION STUDY CENTER			
1730	NO-HOST GET-ACQUAINTED COCKTAIL PARTY	NO-HOST SOCIAL HOUR	NO-HOST SOCIAL HOUR	NO-HOST SOCIAL HOUR		NO-HOST SOCIAL HOUR		NO-HOST SOCIAL HOUR		
1800									NO-HOST SOCIAL HOUR	
1830	DINNER	MEXICAN DINNER	DINNER			DINNER	DINNER AT CASA del MIRADOR	DINNER		
1900				DINNER BAR-B-QUE						STEAK FRY
1930									BANQUET	
2000										
2030	5. DOMESTIC SAFEGUARDS: THREAT ANALYSIS AND RESPONSE CAPABILITIES (JENKINS)	TRAVELOG OF NEW MEXICO	13. ADVANCED SNM ACCOUNTING AND CONTROL SYSTEMS FOR BULK PROCESSING FACILITIES (HIGINBOTHAM, MALANIFY)			21. ASSAY/VERIFICATION OF FRESH AND SPENT-FUEL ELEMENTS (LEE)		29. EXAMPLE OF AN OPERATING STATE SYSTEM - JAPAN (KURIHARA, OSABE)		

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #1: WELCOME

SPEAKER: Dr. Donald M. Kerr

Director, Los Alamos Scientific Laboratory
Los Alamos, New Mexico USA

Tuesday, May 27, 1980
9:00 a.m.

BIOGRAPHY

Education: B.E.E. (Electrical Engineering, 1963); M.S. (Applied Physics, 1964); Ph.D. (Plasma Physics, Microwave Electronics, 1966), Cornell University, Ithaca, NY

Present Position: Director, Los Alamos Scientific Laboratory, 1979-

Past Positions: US Department of Energy, 8/76-7/79; Washington, DC 20585, Deputy Assistant Secretary, Energy Technology (1/79-7/79), Deputy Assistant Secretary, Defense Programs (12/77-1/79), Nevada Operations Office, Deputy Manager (8/76-12/77); Los Alamos Scientific Laboratory, 7/66-8/76 (Energy Division, Test Division, High Altitude Phenomenology Group)

Awards: James Clerk Maxwell Fellowship, 1965-1966; Ford Foundation Fellowship, 1964-1965; National Merit Schclarship, 1958-1962; DOE Certification of Appreciation, December 1977; DOE Outstanding Service Award, July 1979; Who's Who in America, 41st Edition; American Men and Women in Science, 12th, 13th Editions

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #1: WELCOME

SPEAKER: George Weisz

Director, Office of Safeguards and Security
US Department of Energy
Washington, DC USA

Tuesday, May 27, 1980
9:00 & 9:45 a.m.

BIOGRAPHY

Education: B.A., New York University; M.A. (International Economics), George Washington University

Present Position: Director, Office of Safeguards and Security, U.S. Department of Energy, Washington, DC

Present Duties: Responsible for policy direction and conduct of activities required for assuring adequate protection and response capabilities for DOE operations and U.S. energy resources of importance to national security.

Past Positions: Assignments generally related to national security with the Departments of State and Defense in the U.S. and abroad.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #1: WELCOME

SPEAKER: Dr. Adolph von Baeckmann

Director, Division of Development
International Atomic Energy Agency
Vienna, Austria

Tuesday, May 27, 1980
9:00 & 9:45 a.m.

BIOGRAPHY

Education: University of Goettingen, Analytical Chemistry and Inorganic Chemistry, Diplom Chemiker, Dr rer.nat.

Present Position: Director, Division of Development and Technical Support, Department of Safeguards, International Atomic Energy Agency.

Present Duties: Research and Development on international safeguards, co-ordination of related activities in Member States, technical support to IAEA inspectors.

Past Positions: Head of Nuclear Fuel Analytical Laboratory at Nuclear Research Centre at Karlsruhe, FRG, Analytical Chemistry and Radio Chemistry.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 1: WELCOME

Donald M. Kerr
Director, Los Alamos Scientific Laboratory

It is my great pleasure to welcome you to New Mexico and to the beautiful Los Alamos-Santa Fe area that has been selected for this US DOE-IAEA International training course in the vital field of nuclear safeguards. Our fair state of New Mexico -- also known as "The Land of Enchantment" -- is richly endowed, not only with majestic mountains, canyons, and mesas, but it is also rich in energy resources including the key nuclear energy resource -- uranium. In fact New Mexico has a big stake in nuclear power, being the leading uranium producing state in the United States. And as all of you are keenly aware, the future of the nuclear energy option may well depend on how effectively all of us working together can safeguard and control the strategic nuclear materials that fuel nuclear power reactors. The Los Alamos Scientific Laboratory is making significant contributions to all three of the major problems facing the nuclear industry: assured safety, acceptable waste disposal, and effective safeguards; but of these three, improved nuclear safeguards may indeed prove to be the most pressing requirement.

We are proud of the leadership role LASL has played in pioneering modern safeguards R&D and in applying the fruits of this new technology to nuclear plants and facilities throughout the nuclear fuel cycle. As the US Department of Energy's lead laboratory for research and development in nuclear material accountability and control, LASL has developed nondestructive assay instrumentation for accurate and timely measurement of sensitive nuclear materials in all stages of processing. We have designed near-real-time material control and accountability systems based on newly developed measurement techniques and are now demonstrating such a system at our Plutonium Processing Facility. We have also developed the design methodology necessary to implement similar systems in new and existing nuclear fuel cycle facilities.

Los Alamos has the principal responsibility for transferring this developing technology to industry, to our own national safeguards system (both NRC and DOE) and, under appropriate bilateral agreements for cooperation, to other countries. In this role the Laboratory has for many years conducted an extensive program of training courses, technical consultation, and technical support programs in conjunction with the IAEA.

I'm confident that this International Training Course on Nuclear Materials Accountability, sponsored by the US Department of Energy in cooperation with the IAEA, can and will make a significant contribution to effective safeguards training and to the design and implementation of state systems of accountability and control. I wish you every success as you proceed in this important undertaking.

In looking over the very full schedule that Bob Keepin and the Course staff have set up for you, I'm pleased to see that you'll be visiting Los Alamos one week from today. I shall look forward to joining you for the reception at LASL and for your dinner beside the Rio Grande that evening.

SESSION 1: WELCOME

George Weisz
Director, Office of Safeguards and Security
US Department of Energy

Good Morning. I welcome you to this course on behalf of the U. S. Department of Energy, the official sponsor of the International Course on Nuclear Material Accountancy and Control for Safeguards Purposes. We regard our program of international training as a major vehicle for strengthening our international collaboration in safeguards. The course has been prepared and is being held in cooperation with the International Atomic Energy Agency and with consultation of the U. S. Nuclear Regulatory Commission. I am confident that you will find the substantive material presented, the contacts and the exchange of views both informative and useful in your professional work and that it will lead to continuing fruitful exchanges of information and experience between your country, the IAEA, and the United States in the interests of non-proliferation.

SESSION 2a: INTRODUCTION TO TRAINING COURSE

Course Objectives

G. Weisz
U.S. Department of Energy

See Session 1 for biography.

SESSION 2b: INTRODUCTION TO TRAINING COURSE

International and National Safeguards Differences and Similarities

A. von Baeckmann
International Atomic Energy Agency

See Session 1 for biography.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 2c: INTRODUCTION TO TRAINING COURSE

Course Structure and Mode of Operation

G. R. Keepin, Course Director
Los Alamos Scientific Laboratory

BIOGRAPHY

Present Position: Program Manager for Nuclear Safeguards Affairs, Los Alamos Scientific Laboratory

Past Positions: Atomic Energy Postdoctoral Fellow at the University of California, Berkeley and Consultant to Argonne National Laboratory and to Los Alamos Scientific Laboratory. Head, Physics Section, Division of Research and Laboratories, International Atomic Energy Agency, Vienna. Established the Nuclear Safeguards R&D Program at LASL, and served as Group Leader in charge of the Safeguards Program. With the formation of the Energy (Q) Division in 1977 Dr. Keepin became Associate Division Leader for Nuclear Safeguards and Director of Safeguards Programs.

Other Activities: U. S. Delegate to the First United Nations Atoms for Peace Conference in Geneva (1955). IAEA Technical Advisor to the Third United Nations Atoms for Peace Conference in Geneva (1964). Fellow of the American Physical Society and of the American Nuclear Society, and National Chairman of the Institute of Nuclear Materials Management, the leading international professional association in the field of nuclear safeguards and security. He is widely published in the fields of nuclear and fission physics, reactor kinetics and control, and nuclear safeguards technology, and is an internationally recognized authority in the field of nuclear safeguards and nondestructive assay technology.

INTERNATIONAL TRAINING COURSE ON
NUCLEAR MATERIALS ACCOUNTABILITY
FOR
SAFEGUARDS PURPOSES

Session Objectives

SESSION #2: INTRODUCTION TO TRAINING COURSE

Following official welcoming statements on behalf of the major sponsoring organizations, senior officials of the DOE/OSS and the IAEA will present a brief overall orientation to the training course and discuss the purpose and objectives of the course from both the national and the international standpoint. The nature and layout of the course as well as the mechanics of operation in both the lectures and workshop sessions will be explained and any questions answered.

Overall Course Objective

To provide institutional and operational concepts and implementing technology in the area of safeguards accountability that will enable participants to initiate and operate accountability programs in their own countries and thereby serve the national objective of securing nuclear facilities and their materials against unauthorized interference (by subnational adversaries), as well as the international objective of facilitating effective IAEA safeguards.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 2a: INTRODUCTION TO TRAINING COURSE

COURSE OBJECTIVES

George Weisz
Director, Office of Safeguards and Security
U. S. Department of Energy

I. INTRODUCTION

I am happy to be here with you this morning and consider it an honor to represent the U.S. Department of Energy, one of your hosts in this program on nuclear materials accountancy and control. We are most anxious to share with you our recent developments in related technology and methodology and to provide a forum for the IAEA and other countries to do likewise. We hope that your experience here will stimulate and enhance the spirit of international cooperation and collaboration on this subject.

We are most fortunate to have a number of highly-esteemed safeguards experts from around the world gathered together to share their knowledge and their views during the scheduled sessions. We hope and expect that this course will not be limited to one-way communication. Experience with other courses we have sponsored reflects considerable benefit flowing from the "students' participation, i.e., an exchange of views. We know that the LASL personnel who have played a key role in arranging the program for this course and the lecturers, as well as we in DOE, are anxious to have you take part in an exchange of information and ideas. We encourage your questions and comments as the program proceeds, and ask you to feel free to make suggestions about it at the end so that we may improve on it for future offerings.

II. SOME U.S. NON-PROLIFERATION INITIATIVES

This course focuses on an important aspect of non-proliferation--a goal of fundamental importance to the United Staaes and to the international community as well as the IAEA. In fact, this course is mandated by the Nuclear Non-Proliferation Act of 1978, which recognizes safeguards to be one of the pillars of non-proliferation. Section 202 of this act calls for making training available to the international community in both physical security and in safeguards. Two courses on physical protection have been conducted in Albuquerque, in 1978 and 1979. The third is planned for January 1981, again at Sandia. Today begins the first U.S. course on material accountancy and control for domestic and for IAEA safeguards purposes, and it is likely to be repeated annually. It is but one of a number of other related U.S. technical initiatives in support of international safeguards which I would like to describe briefly.

In 1977, the U. S. initiated a program of Safeguards Technical Assistance to IAEA. In response to requests from the IAEA, 116 specific tasks have been completed and 118 are under way. The 118 include 55 new tasks that the Director General forwarded to us last January. Through the end of 1979, almost $15 million had been committed by the U. S. to a program of technology development and equipment for material measurement; containment and surveillance; funding U. S. cost-free technical experts employed by IAEA on a temporary basis; training courses; system studies; information treatment; and inspector operations. Many of the tasks that have been completed have resulted in specific items of equipment being developed for use by inspectors. Types of equipment range from experimental prototypes intended for IAEA evaluation to units now in continuing, routine use by inspectors. These have included hand-held detectors, portable neutron well coincidence counters, and an instrumented vehicle for inspection systems. In the area of nuclear materials measurement instruments, more than 19 different types and categories of equipment have been provided, such as gamma spectrometry and neutron techniques for unirradiated nuclear material and active assay techniques for highly-enriched uranium in fuel assemblies. Nuclear materials containment and surveillance equipment is being provided to give more reliable indication of tampering and more timely indication of diversion. This includes seals, power reactor monitors, TV and camera surveillance systems, and semi-automatic scanners for TV tape and camera film.

Allied with this have been activities devoted to the effectiveness of safeguards for spent fuel reprocessing plants, a matter of concern to IAEA, the U.S., and many other nations as well. For example, back in 1967 and 1969, the IAEA was conducting extensive safeguards exercises at a privately-owned reprocessing facility in West Valley, New York. More recently, the U. S. has benefited from its participation with Japanese and French experts in the series of exercises or safeguards tests conducted at the Tokai-Mura reprocessing plant in Japan during the last two years. Japan had arranged to cooperate with the IAEA on several of these projects several years before we became involved. The U. S. was able to offer several instruments for testing, which will be described later in the course, and Franch undertook several additional projects. Along with the Japanese, the French, and the IAEA, we are now collecting and analyzing data, and preparing reports on Tokai-Mura. The U. S. participants have learned much in this unique example of international cooperation and the parties have decided recently to extend the project another year.

The magnitude of the U. S. commitment to the program and technical assistance to the IAEA, I believe, reveals clearly the keen U. S. interest in IAEA safeguards effectiveness. The Director General and other senior officials of the IAEA have acknowledged the value and importance of this program to the

IAEA. I should be quick to mention that some other Member States have also provided technical assistance to IAEA in safeguards. Indeed, the future effectiveness of IAEA safeguards is highly dependent on such continuing voluntary support by all Member States.

Much of the U. S. technology made available for international application is derived from a broad-based R&D program for domestic safeguards and security through which we have developed, and are continuing to develop a stronger base of technology in physical protection and in materials control and accountability. The responsibility for this program in the U.S. is in the DOE, specifically in the Office of Safeguards and Security. The program involves many government laboratories and several industrial firms. The prime focus of work in physical protection is at Sandia National Laboratories and for materials accountancy, the Los Alamos Scientific National Laboratory. We have an important program on establishment of reference methods, measurement methods, and reference calibration standards in which New Brunswick Laboratory, the National Bureau of Standards, Mound Laboratory, LASL, and other laboratories are heavily involved. This latter effort is vital if the measurements and accountability systems are to have international credibility.

III. COUNTRIES SAFEGUARDS OBJECTIVES

One might ask, what then is the role for a nuclear materials accountancy and control system in a country's domestic system? It may be helpful if we discuss safeguards objectives, first, in terms of each country's domestic needs, which are to address sub-national adversaries intending malevolence against peaceful nuclear programs; and, second, in terms of the very important role of facilitating IAEA safeguards, which are to address the required political assurance that no country is using declared peaceful programs as a mask to cover military program diversion.

In the context of a country's domestic system, the initial safeguards goal is to deter attempted malevolent acts. If that should fail, the goal is to detect rapidly the attempt and respond quickly so that adverse consequences can be either prevented or minimized. Finally, the country is concerned with pursuing, apprehending, and punishing adversaries. It should be clear from this description that the country's physical protection and police powers are the primary tools to address the prevention and rapid reaction to alarm sequences.

Nuclear materials accountancy and control include periodic inventories of nuclear materials and thereby provide the country with confirmation over the long term that its entire integrated system of physical protection and materials control has worked effectively. It does this by verifying that materials are present in the correct amounts at the assigned locations. Further, it provides a mechanism to limit access to authorized individuals and provides a measure of deterrence by raising the probability that an attempted diversion will be detected. Moreover, if a subnational diversion were to somehow escape the physical protection and materials control preventive and rapid response capabilities, then the nuclear materials accountancy system should be able to provide information of extreme value to law-enforcement authorities in connection with their mission of identifying and apprehending the adversaries. The nuclear materials accountancy and control system in such a mode can help identify the precise location in a process and the time when the diversion or theft took place and the access by personnel to sensitive materials.

The same nuclear materials accountancy system also provides an extremely valuable base for the IAEA safeguards mission. The IAEA's objective, which will be discussed at greater length by expert speakers, is to assure, through independent inventory verification, that the nuclear materials subject to IAEA safeguards in the quantity and type identified in official records for a particular peaceful use activity are indeed there and to conclude, with reasonable confidence, that they are not being used for other than authorized purposes. Needless to say, IAEA has no responsibility for law enforcement and, as a consequence, cannot make use of those elements in an accountability system which could help law-enforcement authorities in isolating the time and place of a theft to assist in the apprehension of the thief.

Capabilities for detecting a theft or other anomaly are being improved. The trend in technology is towards greater emphasis on automated, remote measurements for accountability in order to reduce access and exposure of people to SNM and to minimize material holdup in process equipment. Through the use of microprocessors and near real-time accountability, the demands on the operator for inputting and monitoring accountability data can be reduced further. Continuing work is devoted to improving nondestructive assay (NDA) and conventional analytical methods for safeguards purposes, and the standards upon which they are based. These developments can improve IAEA capability for independent verification. However, nuclear material accounting systems will have to contend with an increasing diversity of materials and process flow sheets, facility and operational constraints, the needs for greater accuracy, sensitivity and timeliness, and less hands-on operation and maintenance.

Improvements in equipment to control and monitor access to facilities and to special nuclear material will continue. Where testing in our laboratories reflects that the sensitivity, reliability, or durability of commercial instruments is inadequate, modifications for improvement or alternative techniques are explored.

The thrust of our safeguards research and development reflects requirements identified by the various DOE Nuclear Program Managers. This requires examination of concepts, designs and equipment to safeguard, for example, spent fuel storage, production reactors, and various processing facilities. With respect to the breeder program, our laboratories are developing technology which will support maintaining the breeder option as indicated by U. S. Administration policy.

The DOE structure places the responsibility for meeting facility safeguards and safety requirements with DOE program and field office officials. A major part of our R&D effort is to assist these managers and their staffs in the effective use of the technology derives. We now have an active systems implementation program that is directed toward adapting for practical use the most advanced safeguards and security technology at existing facilities and in the design of new facilities.

The results of the International Nuclear Fuel Cycle Evaluation Program (INFCE) have also pointed out that various facilities and technologies are subject to being misused and for this reason it is important to plan future fuel cycles with careful attention to proliferation risks. There is a need for us to ensure that new safeguards-related developments are completed and incorporated in the early designs of future fuel cycle facilities. In order to gain acceptability in the political and international arena, we will need to demonstrate that future large-scale facilities and special nuclear material can be protected and independently verified by IAEA. This requires continued improvements in the accountability, and containment and surveillance technology.

IV. THE TECHNICAL CHALLENGE

Throughout the fuel cycle, nuclear material presents itself as an elusive target for accounting--it is bred or fissioned, changes form and has many different isotopes, material forms and values. It is thus the challenge of all of us to provide the technology and strategy needed to characterize and quantify the material and report its true inventory as early as can reasonably be done.

New developments in such areas as nondestructive assay, automated measurements, computerized data management, and display have added new dimensions to nuclear materials accountancy and control capabilities. Advanced techniques have been developed for measuring material on-line in its various forms (liquid and solid product, scrap, and waste). These refinements furnish the facility operator and safeguards authorities with accurate and timely information concerning the disposition of nuclear materials (its form, content, and location). While you are here, you will have the opportunity to see some of these recent developments. Included are the Californium 252 Shuffler (an active neutron measurement system for enriched uranium) and a densitometer that measures both total plutonium and total uranium. Chemical assay continues to be a very important validation and inventory verification technique and efforts are being made to make it remote, automated and more timely.

V. FUTURE NEEDS

So, new and old safeguards technology and strategies need to address today's challenge of material accountancy. There are a variety of important problems needing attention, for example, large spent fuel storage pools, complex fuel fabrication facilities, and unique plutonium research facilities. Recent important activities include experiments designed to improve the capability for deducing the burnup of spent fuel. Near real-time accounting systems utilizing key measurement points and central computer recording and reporting have been developed. One example is the Dynamic Material Accounting and Control System (DYMAC) which was developed by Los Alamos and which you will see and hear more of during your stay. Also, new strategies for safeguarding Zero Power Plutonium Reactors will be employed using an accountancy system integrated with containment and surveillance.

We will all need to dedicate ourselves to face the safeguards problems of the future--that of large spent fuel storage sites and new fuel cycle facilities. It is hoped that your experience here will help strengthen your foundation of knowledge and ideas from which to solve safeguards problems as they arise in the future. Thus, as we begin these two weeks here, let us together seek to achieve and maintain effective safeguards for the good of nuclear nonproliferation.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 2b: INTRODUCTION TO TRAINING COURSE

INTERNATIONAL AND NATIONAL SAFEGUARDS DIFFERENCES AND SIMILARITIES

A. von Baeckmann
International Atomic Energy Agency

I. INTRODUCTION

In nuclear industry the word safeguards is often used to describe activities of national Authorities to control nuclear energy and protect it against theft or misuse by individuals or groups of individuals who may use nuclear energy in order to threaten or blackmail citizens and communities or to use nuclear energy for other terrorist purposes or against other dangerous incidental events. The same word is also used for activities of the International Atomic Energy Agency aiming at the prevention of the horizontal proliferation of nuclear weapons. During recent years I have observed that the two meanings of the word "safeguards" have been confused and it is therefore my intention at the beginning of this training course to clarify this subject to avoid unnecessary misunderstanding.

The IAEA safeguards system was established in the late 50's and early 60's when the IAEA started its promotional activities. At that time it was felt that the peaceful utilization of nuclear energy should contribute significantly to the welfare and industrial development of nations and that therefore the knowledge of its peaceful utilization should find the widest distribution. You will remember that in those years the "Atoms for Peace" Programme was initiated. At the same time several States expressed their concern that nuclear energy could be misused for non-peaceful purposes and an international consensus was arrived at that reasonable control was necessary to maintain sufficient assurance that nuclear energy would not be misused. In particular, countries supplying nuclear material, equipment, facilities, or technologies were concerned that their delivery could lead to a nuclear weapon capability in the recipient countries. A safeguards system was therefore designed by which IAEA inspectors would verify that materials, components, or technology delivered by supplier countries were not misused by "furthering any military purposes." This safeguards system is described in the IAEA document INFCIRC/66/Rev. 2[1] and is applicable to materials, equipment, etc., listed in a special inventory list.

In the late 60's it became obvious that the limited application of international safeguards to items on the inventory list was insufficient to prevent the further proliferation of nuclear weapons. In the United Nations, the Non-Proliferation Treaty[2] was negotiated and opened for signature. Article 3 of this Treaty requires each non-nuclear-weapon-State party to the Treaty to conclude a Safeguards Agreement with the IAEA by which all peaceful nuclear activities in the country would be submitted to IAEA safeguards. A special Safeguards Committee elaborated "The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons." The conclusions of the Safeguards Committee have been published in the IAEA document INFCIRC/153.[3] The basic undertaking of the State concluding a safeguards agreement in accordance with NPT is defined in Article 1 of this document as follows: "The Agreement should contain, in accordance with Article III.1 of the Treaty on the Non-Proliferation of Nuclear Weapons, an undertaking by the State to accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within its territory, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices."

The major difference between the two IAEA safeguards systems is that under agreements concluded in accordance with INFCIRC/66 IAEA safeguards are applied to specific items listed on the inventory, whereas in States which have concluded agreements in accordance with INFCIRC/153, all source and special fission material in all nuclear activities are subject to IAEA safeguards. INFCIRC/153 type safeguards agreements are therefore called "full scope" safeguards agreements.

The need to control nuclear material against misuse by terrorists or against other dangerous incidental events had also been realized from the very beginning of the utilization of nuclear energy. Several States have established National Safeguards Authorities and elaborated relevant regulations and laws. Besides aspects of health and safety, environmental protection, proper utilization, and physical protection of nuclear materials and facilities, the physical control over the nuclear material is also usually covered by the relevant regulations. The Member States of the European Community have delegated responsibility for issuing and administering regulations in some of these areas to the Commission of the European Communities (EURATOM). Other States have established National Safeguards Authorities or decentralized authority bodies. In each case the scope of the responsibility of the relevant authority has been defined, although the designated responsible authority for nuclear material accountancy and control is not always the same body as the designated authority for physical protection or health and safety regulations or for licensing of nuclear facilities.

In the following paragraphs, I will try to compare objectives, authorization, enforcement, and mode of operation of the IAEA safeguards system with those of National Authorities.

II. OBJECTIVES OF SAFEGUARDS

The objective of IAEA safeguards must be viewed in the light of world community concern about horizontal proliferation of nuclear weapons. IAEA safeguards should be understood as one of the major components of the international non-proliferation policy. If there should be a case where a State acted in violation of its non-proliferation undertaking, the IAEA safeguards system must be capable of detecting in a timely manner the diversion of a significant quantity of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown and to deter such diversion by the risk of early detection (Article 28 INFCIRC/153) and in case of non-diversion it must be capable to ascertain that there has been no diversion of nuclear material from peaceful uses to nuclear weapons or other nuclear explosive devices (Article 7). The objective of IAEA safeguards therefore is to be two-fold. First to deter States who are parties to the Agreement from violating their non-proliferation obligation and second to increase mutual trust between States with regard to their declared intentions of using nuclear energy for peaceful purposes only.

As I have indicated earlier, the objectives of the National Safeguards System are to keep control over the utilization of nuclear energy in the State in order to avoid terrorism, blackmail, danger to the health and safety of the population and severe financial losses. The activities of the national safeguards system therefore focus not only on the detection of diversions or misuse of nuclear energy--as the IAEA system does--but also on their prevention and on remedial measures like the recovery of stolen material, etc.

III. AUTHORITY

Authority for the application of IAEA safeguards is based on safeguards agreements concluded between States and the IAEA. Article III, A5 of the Statute of the IAEA[4] authorizes the Agency "To establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy."

INFCIRC/66 contains provisions for the acceptance and application of safeguards which are incorporated, by reference, into safeguards agreements as required. INFCIRC/153 contains the outlines of agreement provisions which must be embodied in NPT safeguards agreements.

Authority for the application of National Safeguards comes through the responsibility of any Government for public safety and welfare. Within its own rights, the State establishes the necessary Authorities and regulations. International agreements may also require the establishment of national safeguards systems, for example bilateral cooperation agreements, or supply agreements. Safeguards agreements concluded with the IAEA in accordance with INFCIRC/153 require that "The State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards under the agreement" (Paragraph 7). The IAEA is in the process of issuing guidelines for establishing and maintaining States systems of accounting for and control of nuclear material. These guidelines describe only those components of the national safeguards system which are directly related to and required for the application of international safeguards, including chapters on authority and responsibility, laws and regulations, information systems, requirements for nuclear material accounting and control, ensuring compliance, and on technical support, both on the level of a State and on the level of a facility. The IAEA has also issued recommendations for the physical protection of nuclear material (INFCIRC/225)[5] and promoted the institution of a convention on physical protection which has been opened for signature recently at IAEA Headquarters.[6] Other activities of the National Safeguards System in the field of Health and Safety are supported by numerous publications of the Agency in the Nuclear Safety Series.[7]

IV. ENFORCEMENT

Whereas the National System has at its disposal all the authority and powers at the command of the national Government (for example: guards, police force, military forces, courts, imprisonment, fines, withdrawal of license, etc.), IAEA safeguards has the moral backing of world public opinion and the Agency can reasonably expect appropriate action on the part of the United Nations, a group of States, or individual States should it find a State to have appeared to have acted in breach of its safeguards agreement. In such an event the Director General of the IAEA would inform the Board of Governors of the situation and the Board, in turn, would seek to establish if a violation had taken place and, if so, the seriousness of the violation. If necessary, the case would be reported to the Security Council of the United Nations.

V. SAFEGUARDS MEASURES

The measures applicable by the IAEA in implementing its safeguards system are described in the relevant safeguards agreement. IAEA safeguards rely heavily on material accountancy supported by containment and surveillance measures. The nuclear material accountancy system of the Agency is based on reports submitted by the National Safeguards Authorities and on records kept at facilities. These cover the inventory changes as well as physical inventories and material balances. IAEA inspectors verify the correctness of the records and reports at the facilities through independent measurements or observations.

National Safeguards Authorities, inter alia, are responsible for the compliance of facility operations with the requirements of the international safeguards agreements. This includes proper record keeping and reporting,and establishing and maintaining, for nuclear material, proper measurement capabilities which must comply to the latest international standards. They are also responsible for organizing access of IAEA inspectors and providing the necessary support required for IAEA inspectors to discharge their duties. Where necessary they are also responsible for support to IAEA inspectors in the application of containment and surveillance measures. In order to assure correct nuclear material accountancy, National Safeguards Authorities may perform independent control and evaluation activities. In addition, appropriate measures should be applied by the National Authorities to control the compliance of plant operators with national regulations and other requirements. This includes, in particular, regulations on the physical protection of nuclear materials and facilities aiming at:

a) the prevention of diversion of nuclear material, terrorists actions against nuclear facilities or other dangerous incidental events,

b) the immediate detection of those events, and

c) remedial measure in case these events have been detected.

For example: police force response to terrorists attacks or recovery of stolen material, etc.

V. CONCLUSION

In conclusion, I hope that these comparative listings of objectives, authorities, enforcements and safeguards measures clearly identify the differences and similarities of the international safeguards system and the national safeguards system. Having different objectives and different authorities, both systems utilize similar safeguards measures. Whereas the efficiency of IAEA safeguards strongly depends on the functioning of the national safeguards system, the national safeguards system is usually significantly supported by IAEA activities.

We expect that participation in this course will assist you in establishing and improving the national safeguards system in your own country to the benefit of your national requirements as well as your international obligations. In particular we hope that this course will improve the performance of your national system for nuclear material accountancy and control so that international safeguards can be applied in a more easy, less intrusive, and more effective manner. Nuclear energy is one of the most important and possibly the most powerful energy resource we can rely on in the future and its use for peaceful purposes only is an aim we must continue to pursue. Not only prosperity and public welfare but also world peace and stability may depend on its full exploitation. If we want to promote this important matter--and I think we should all want to promote it--we have to create the necessary atmosphere of trust and confidence. The IAEA safeguards system aims at establishing a high degree of credibility with regard to the peaceful intentions of its Member States in the utilization of nuclear energy. National Safeguards Systems are required if confidence is to be created in the capability of States to cope with the risks of nuclear energy. I hope that this course will contribute to improve both systems.

REFERENCES

1. The Agency's Safeguards System (1965, as provisionally extended in 1966 and 1968), IAEA INFCIRC/66/Rev. 2, 1968.

2. Treaty on the Non-Proliferation of Nuclear Weapons, IAEA INFCIRC/140, 1970.

3. The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, IAEA INFCIRC/153 (Corrected) Reprint 1972.

4. Statute of the International Atomic Energy Agency (Amended)

5. The Physical Protection of Nuclear Material, IAEA INFCIRC/225/ Rev. 1.

6. Convention on Physical Protection of Nuclear Material, IAEA INFCIRC/274 (1979).

7. The Agency's Safety Standards and Measures, IAEA INFCIRC/18/Rev. 1, IAEA Safety Standards, IAEA Safety Guides.

SESSION 2c: INTRODUCTION TO TRAINING COURSE

COURSE STRUCTURE AND MODE OF OPERATION

G. Robert Keepin
Los Alamos Scientific Laboratory

Introduction

To the warm welcome already extended by Don Kerr, George Weisz, and Adolph von Baeckmann, may I add my own greetings and welcome on behalf of the Training Course lecturers and staff. We are extremely pleased and honored to have such excellent participation from throughout the worldwide nuclear community -- representing some 26 countries and two International Organizations.

Coming from many different countries with uniquely different energy needs, each of us is bound to have a somewhat different viewpoint and approach to the issues and the problems of nuclear energy -- including the issues of nuclear safety, waste management, and specifically the issue of safeguards and control of nuclear materials, which we will be addressing together in this training course. The point I want to stress is that despite our many differences, we are all here because we share a common concern and commitment to effective safeguards of nuclear materials as a necessary requirement for the continued growth of nuclear power as a major energy source for the benefit of man.

Now by way of introduction to the course curriculum, I'd like to give you a brief preview of what you can expect during the next nine days of the course. We'll take an overall look at the course structure, its components, the materials and facilities you will be using, areas of emphasis, and finally the culmination of the course in a safeguards design workshop -- what might be called the "product" of the course. Following the workshop will be a discussion and evaluation of the workshop and the overall course -- how useful it was to you and how well it matched your needs.

Purpose and Emphasis

First let me state the purpose of the course very simply as shown in Vugraph 1. To this I would add a clarifying statement concerning the major areas of emphasis in the course (Vugraph 2).

In structuring the course and selecting the lecture staff, we attempted to meet the anticipated needs of course attendees. We are hopeful that our anticipation of needs will correspond reasonably well with your requirements and areas of professional interest. Recognizing the diversity of backgrounds and specialty areas represented in the student body, we will try, insofar as possible, to make adjustments in the oral presentations as may be required to better meet your overall needs. Toward this end we actively solicit your comments, suggestions, and feedback throughout the course on how well we're doing and what changes you feel that might be appropriate.

Course Structure

The basic course structure is outlined as shown in Vugraphs 3-6. The first week (Sessions 1-17) covers the general principles and practice of safeguards -- its evolution, basic elements and current application of materials accountability and control, inspection and verification on the national and international level, and current practice in specific types of nuclear facilities. The first week then concludes with a review of the material covered and a preview of the Workshop in facility safeguards system design to be conducted during the last two days of the course.

Whereas in the first week extensive technical detail is purposely avoided, in the second week we go into more detail on the instrumentation and technology required to implement modern safeguards systems. The lecture material is correlated with, and supported by, tours and demonstrations (at the Los Alamos Safeguards R&D Laboratories) of state-of-the-art instrumentation and equipment. Detailed descriptions are given of current safeguards practice and actual operating experience in existing power reactor and research reactor facilities. The principles and practical application of safeguards system design are then presented and the resources required for their implementation are surveyed.

The second week of the course culminates in the "product" of the course -- the workshop in facility safeguards system design, in which each of you will have an opportunity to participate directly as a member of a designated design subgroup. More information on the workshop, its scope, and mode of operation will be provided in the preworkshop Session 17 on Friday, May 30. The course concludes with an evaluation of the design workshop results and an overall evaluation of the entire course. As a part of the evaluation process, participants will be asked to complete a comment and critique form that is intended to identify the strengths and weaknesses of the course, and thereby enable indicated improvements to be made in future course offerings.

Course Components, Materials and Facilities

Now I want to turn to the most important part of my talk--namely the basic components or "building blocks" of this course. It is important that you understand and become familiar with the nature and function of these components (discuss Vugraph 7). Equally important are the mechanics of operation of the course and the materials and facilities we will be using (discuss Vugraph 8). Following the presentation and discussion of course components, mode of operation, materials and facilities, specific questions and concerns of the participants will be solicited and directly addressed.

Communication and Effective Information Exchange

In any activity such as this involving detailed information transfer and exchange (i.e. two-way exchange), it is obvious that effective communication is absolutely essential to the success of the entire effort. And we all know from experience that even under the best of circumstances, and indeed even when there are no language or cultural differences, the accurate and effective transfer of information -- technical or otherwise -- can sometimes be difficult and frustrating. You're probably familiar with the expression: "The message received is not always the message given". or its equivalent in your own language. (In my oral presentation I will relate a little story about a PIG that rather dramatically illustrates how communication problems can lead to most unfortunate consequences.) Clearly communication problems can, and do, arise even when there's only one language involved, so it's certainly not surprising that the difficulties of communication are often multiplied manyfold when two or more languages are involved.

Past experience in giving international courses such as this has shown that language difficulties can indeed be formidable for some participants, and with this in mind we've asked our lecture staff to be mindful of the language factor and to speak clearly, slowly, and to make maximum use of visual presentations, vugraphs, etc., during their oral presentation. We've tried to allow ample time for questions and discussion following each lecture, and we urge participants to take full advantage of the question periods for further clarification of session topics. To further encourage direct interaction and effective communication between students and lecturers we have purposely established a relatively "open" course schedule with frequent breaks and extended "free time" intervals (e.g. during and after lunch and dinner) during which we encourage students and lecturers to get together for productive discussions. We also hope that participants will find it possible to devote a nominal hour or two per day to individual study of the lecture material in the course manual, review of session notes, etc.

It is important to recognize that there will inevitably be duplicate coverage of some overlapping topics by different lecturers, and furthermore that certain differences in viewpoint and approach to a given topic will sometimes be apparent among different lecturers. This very diversity is in fact a part of the reality of safeguards today, and it clearly underscores the great need for consensus, international cooperation, and standardization in the implementation of equitable, effective safeguards on both the national and international level. Indeed, this need is an important underlying factor in the basic thrust and overall purpose of this international training course.

As noted previously, we are all keenly aware that each of our own countries has a unique set of energy problems -- with correspondingly unique national concerns and approaches to the issues of nuclear energy. We're also aware that many countries represented here have expanded nuclear power programs either planned or already underway. It is our hope that the formal lecture presentations, the safeguards design workshop, and the informal interactions and discussions among all participants -- students and lecturers alike -- will prove of genuine value to you, and indeed to all of us, in implementing effective safeguards systems in our various countries.

In closing I'd like to express the sincere hope that the common concern and professional commitment to effective safeguards that has brought us together here at historic Bishop's Lodge near Santa Fe may provide a unifying spirit and an overall theme of collegiality among all participants in this international training course.

Vugraph #1

PURPOSE OF COURSE

TO PROVIDE PRACTICAL TRAINING IN THE DESIGN, IMPLEMENTATION AND OPERATION OF A NATIONAL SYSTEM OF NUCLEAR MATERIAL ACCOUNTABILITY AND CONTROL THAT SATIFIES BOTH NATIONAL AND IAEA INTERNATIONAL SAFEGUARDS OBJECTIVES.

Vugraph #2

COURSE EMPHASIS

MAJOR EMPHASIS:

REQUIREMENTS AND IMPLEMENTATION OF A NATIONAL SYSTEM FOR POWER REACTOR, RESEARCH REACTOR AND SPENT FUEL STORAGE FACILITIES.

(INVENTORY DOMINATED--ITEM CONTROL ACCOUNTING)

SECONDARY EMPHASIS:

REQUIREMENTS AND IMPLEMENTATION OF OTHER FUEL CYCLE COMPONENTS SUCH AS BULK HANDLING FACILITIES

(FLOW DOMINATED--BULK MEASUREMENT/ACCOUNTING)

Vugraphs #3 & 4

COURSE STRUCTURE

FIRST WEEK

HISTORICAL AND LEGAL REQUIREMENTS FOR SAFEGUARDS
- HISTORY AND POLITICAL BACKGROUND
- STATE SYSTEM -- DESCRIPTION; NEED FOR; CAPABILITIES

NATIONAL, MULTINATIONAL AND INTERNATIONAL SYSTEMS
- NATIONAL (E.G. US)
- EURATOM (CEC)
- IAEA (3 LECTURES)

BASIC ELEMENTS OF NUCLEAR SAFEGUARDS
- FUEL CYCLES
- ELEMENTS OF NUCLEAR MATERIAL ACCOUNTING
- ELEMENTS OF NUCLEAR MATERIAL CONTROL
- STATISTICAL METHODS
- ADVANCED SYSTEMS FOR BULK FACILITIES

NUCLEAR SAFEGUARDS IN SPECIFIC TYPES OF FACILITIES
- POWER REACTORS/SPENT FUEL STORAGE
- RESEARCH FACILITIES

PREWORKSHOP SESSION (AND REVIEW)

Vugraphs # 5 & 6

SECOND WEEK

BASIC SAFEGUARDS MEASUREMENT TECHNOLOGY
- CHEMICAL ASSAY
- NONDESTRUCTIVE ASSAY (NDA)
- STANDARDS
- NDA OF FRESH AND SPENT FUEL

TOUR/DEMONSTRATION OF SG EQUIPMENT/FACILITIES
- LECTURE/TOUR
- DEMONSTRATION OF NDA INSTRUMENTATION

OPERATING SAFEGUARDS SYSTEMS IN EXISTING FACILITIES
- LWR POWER REACTOR
- CANDU POWER REACTOR
- RESEARCH REACTORS

DESIGN, IMPLEMENTATION, OPERATION OF STATE SYSTEMS
- SYSTEM DESIGN, FEATURES AND APPLICATIONS
- OPERATING STATE SYSTEMS, (GDR, JAPAN)
- IMPLEMENTATION OF FACILITY SAFEGUARDS SYSTEM

WORKSHOP IN FACILITY SAFEGUARDS SYSTEM DESIGN
- REFERENCE FACILITY DEFINITION
- DESIGN CONSIDERATIONS/INPUT
- DEVELOPMENT OF FACILITY DIQ.
- NEGOTIATION OF FACILITY ATTACHMENTS
- SYSTEM DESIGN EVALUATION AND COMPARISON

CONCLUSIONS; COURSE EVALUATION; WRAPUP

Vugraph #7

COURSE COMPONENTS

LECTURE PRESENTATIONS AND DISCUSSIONS
COURSE MATERIALS
WORKSHOP SESSIONS (#17, 31 and 32)
RESOURCE MATERIALS/VIDEO PLAYBACK
TOUR AND DEMONSTRATION OF SG EQUIPMENT/FACILITIES
INDIVIDUAL STUDY/CONSULTATION
PROFESSIONAL AND SOCIAL INTERACTIONS/ACTIVITIES

Vugraph #8

COURSE MATERIALS AND FACILITIES

COURSE MANUAL/LECTURE TEXTS

COURSE WORKBOOK/PRESENTATIONS
- COURSE SCHEDULE
- SESSION LECTURERS AND BIOGRAPHIES
- SESSION OBJECTIVES
- SESSION VUGRAPHS AND SLIDES
- SESSION NOTES

TOUR/DEMONSTRATION OF SG EQUIPMENT/FACILITIES

RESOURCE MATERIALS
- VIDEO TAPE LIBRARY
- TV MONITORS (3)
- DOCUMENTS AND REPORTS

ADMINISTRATIVE/TRAVEL ASSISTANCE

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #3: HISTORICAL AND POLITICAL FRAMEWORK OF SAFEGUARDS

SPEAKER: Dr. Gerald F. Tape

President, Associated Universities, Inc.
Washington, DC USA

Tuesday, May 27, 1980
11:00 a.m.

BIOGRAPHY

Education: Eastern Michigan University, Physics, AB 1935; University of Michigan, Physics, MS, 1936, PhD 1940.

Present Position: President, Associated Universities, Inc.

Present Duties: Chief executive officer, AUI Manages Brookhaven National Laboratory for Department of Energy and National Radio Astronomy Observatory for National Science Foundation.

Past Positions: US Representative to IAEA (73-77); Commissioner US AEC

Received Henry DeWolf Smyth Nuclear Statesman Award 1978

Session Objectives

SESSION #3: HISTORICAL AND POLITICAL FRAMEWORK OF SAFEGUARDS

The role of nuclear materials safeguards as a principal element in making possible wide civil applications of nuclear energy will be presented. Emphasis will be placed on the interaction of technical and political capabilities and constraints and, more specifically, on the roles of state and international systems. More recent technical, institutional, and political developments as they may impact on nuclear safeguards systems will be considered.

After the session, participants will be able to

1. Provide the rationale and justification for employing both national and international nuclear materials safeguards systems and the need for coordination.

2. Trace the development of the IAEA and its role in making possible international cooperation where special nuclear materials are involved.

3. Describe the interdependence of technology, institutional arrangements (including treaties), and national policy in international cooperation and achievement of nonproliferation goals.

SESSION 3: HISTORICAL AND POLITICAL FRAMEWORK OF SAFEGUARDS

Gerald F. Tape
Associated Universities, Inc.

I. INTRODUCTION

Concern for the misuse of atomic energy has been with us since the dawn of the atomic age. In the early 1940s the scientists' self-imposed control on the then sensitive nuclear information was soon followed by the rigorous policy of classification. With the end of World War II and the early recognition of benefits to be obtained from nuclear developments in the civilian sector, new initiatives were needed; extensive security classification was not the long-term answer. Furthermore, the "facts of nature" could not indefinitely remain known only to a few; they were there for all who would devote the effort and investment to seek them out.

Control in the non-peaceful use of atomic energy has a long history. In November 1945, the President of the United States, the Prime Minister of the United Kingdom and the Prime Minister of Canada stated that international control of the whole field of atomic energy was immediately essential. To quote a portion of their statement:

> "We are aware that the only complete protection for the civilized world from the destructive use of scientific knowledge lies in the prevention of war. No system of safeguards that can be devised will of itself provide an effective guarantee against production of atomic weapons by a nation bent on aggression. Nor can we ignore the possibility of the development of other weapons, or of new methods of warfare, which may constitute as great a threat to civilization as the military use of atomic energy."

From these concerns, there followed a series of international activities culminating in the convening of the United Nations Atomic Energy Commission to consider steps that might be taken to assure the control of atomic weapons. It was there in July 1946 that the U.S. Representative, Mr. Bernard M. Baruch, set forth a plan based upon the Acheson-Lilienthal study. A far-reaching scheme for placing all sensitive nuclear activities under international ownership-management was envisioned. The plan was intended to permit and encourage peaceful uses, while banning military applications even by the U.S. itself, the then sole possessor of atomic weapons.

The U.S. proposed the creation of an International Atomic Development Authority, to which would be entrusted all phases of the development and use of atomic energy, starting with raw material and including

- o managerial control or ownership of all atomic-energy activities potentially dangerous to world security;
- o power to control, inspect and license all other atomic activities;
- o the duty of fostering the beneficial uses of atomic energy; and
- o research and development responsibilities of an affirmative character intended to put the Authority in the forefront of atomic knowledge and thus enable it to comprehend, and therefore to detect, misuse of atomic energy.

It was recognized that, to be effective, the Authority must itself be the world's leader in the field of atomic knowledge and development and thus supplement its legal authority with the great power inherent in possession of leadership in knowledge.

The Baruch Plan for internationalizing the atom was farsighted. It set forth the need for restraint in nuclear weapons development and for international safeguards and penalties for diversion in civil nuclear programs. Forgoing manufacture and possession of atomic bombs was a key element of the plan. Soviet opposition led to its rejection, and secrecy continued as the fundamental nuclear policy not only of the U.S. but of other nations as well.

By the early 1950s, it was recognized that the national security classification route could not prevent the steady dispersion of nuclear weapons capabilities. The facts of nature were available for discovery by those who sought them, and they were being acquired. Advanced technologies that could support a nuclear weapons program were being developed or acquired by a number of nations. Many nations, recognizing the benefits to be gained from various nuclear applications, initiated their own indigenous programs. Nuclear power was approaching a stage of practical application, a situation which would lead many countries to engage in nuclear activities even though they had no then present interest in developing nuclear weapons. Without constraints and international understandings, both civil and military objectives would have proceeded simultaneously. A new approach was needed.

The U.S. decided on a major change in its policy. In December 1953, President Eisenhower proposed that there be international cooperation in the peaceful use of nuclear energy under controls to assure that this cooperation would not be diverted to military uses. He also proposed the creation of an international atomic energy agency, which would be the focal point of both the cooperative programs and the international control machinery. The Eisenhower plan differed from the earlier Acheson-Lilienthal concept in one very important respect. Unlike the earlier plan, the new proposals did not call for international ownership and management of sensitive activities. Instead, it contemplated national programs under international safeguards, a system of inspection and control designed to sound the alarm in case any diversion to military uses took place. The implicit assumption was that world reaction to such a serious violation of the rules would deter violations in most cases, and deal effectively with any which might occur.

The Eisenhower Atoms for Peace proposals were generally adopted by the Congress through passage of the Atomic Energy Act of 1954, the same legislation which authorized private civil nuclear activities, including nuclear power, in the U.S. Domestic and international programs and policies were of necessity intimately related from the outset, since a program of international nuclear cooperation could not have been undertaken in the absence of a strong domestic base.

Both the domestic and international peaceful nuclear programs developed quickly after 1954. A domestic nuclear power industry was inaugurated; Shippingport was placed in operation in 1957; and the first privately owned plants were started soon after. Internationally, the U.S. concluded its first cooperative agreements in 1955. The first Geneva Conference on the Peaceful Uses of Atomic Energy was held in the same year, and the International Atomic Energy Agency (IAEA) was established in 1957, near-record time for an international undertaking of this type.

The U.S. was not alone in its efforts to create a new regime based on cooperation under effective controls. Other countries with nuclear capabilities adopted similar policies, and in some important respects preceded the U.S. in their practical application.

As time went on, the fabric of international cooperation and control was strengthened. The novel concept of on-site inspections to assure that no diversion was taking place was not only incorporated into international agreements but put into practice, first by the U.S. bilaterally and later by the international staff of the IAEA. Most countries with nuclear capability adopted the policy of furnishing nuclear assistance only on the condition that it be subject to these safeguards. The U.S. and other suppliers went to great lengths to offer reliable long-term nuclear fuel supply assurances so as to discourage the development of independent sources of supply. As a result, the bulk of the nuclear activities in the world came under this regime, even though there was no legal barrier to any nation's pursuing independent nuclear programs and developing nuclear weapons if it chose to do so. During this period, two additional nations--France in 1960, and the Peoples Republic of China in 1964--developed nuclear explosives, through independent programs dedicated to that purpose. Thus the policy of offering peaceful nuclear assistance under safeguards appeared to be accomplishing its objective of restraining proliferation, if not avoiding it completely.

II. THE INTERNATIONAL ATOMIC ENERGY AGENCY

Launched in response to President Eisenhower's 1953 "Atoms for Peace" appeal for the establishment of an international organization to devise methods whereby "fissionable material would be allocated to use in the peaceful pursuits of mankind," the International Atomic Energy Agency came into existence in 1957 with two basic objectives. Their formulation in the Agency's Statute (Article II) reads as follows:

> "The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout th world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose."

These are still valid and worthy objectives. They reflect the conflict between the military atom and the peaceful atom; they reflect technical and political realities. They set goals for mankind; on the one hand, to exploit for his benefit a resource of nature through the application of technology in the utilization of nuclear energy, yet, on the other hand, to apply constraints to ensure that such benefits are not realized at the expense of a safe and peaceful coexistence among all inhabitants on this planet.

The Statute is the legislative document upon which the IAEA is founded. It provides for holding of an annual General Conference to which all Member States of the Agency can send delegates. The General Conference has power to discuss any matters relating to the Statute or arising from its implementation. A Board of Governors, created with the authority to carry out the functions of the Agency in accordance with the Statute, reports to the General Conference annually on the Agency's conduct of its affairs. The Statute also provides for the appointment of the Director General as the chief administrative officer of the Agency, responsible to the Board for ensuring that its decisions are effectively carried out.

Over the years the work of the Agency has changed, not in scope but in emphasis. The early demands for information, training, equipment and expert assistance have grown. Nuclear power has become of increasing importance to all nations where new energy resources are now so much in demand. The application of safeguards has been found to be more complex, especially for bulk handling facilities, and additional mechanisms for the assurance of non-diversion are being investigated. The designation of the IAEA by the Non-Proliferation Treaty as the agent for international safeguards has increased the Agency's work load.

III. THE NON-PROLIFERATION TREATY

The Non-Proliferation Treaty (NPT) came into force in 1970. Review conferences are held every five years, the next one is scheduled for Geneva this fall. There are now 112 parties to the Treaty; there still remain a number of important nations that have not acceded.

Non-Nuclear Weapons States (NNWS) parties to the Treaty have pledged not to acquire or manufacture nuclear weapons. Further, a NNWS party agrees to place its nuclear activities under safeguards for "the exclusive purpose of verification of the fulfillment of its obligations assumed under the Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other explosive devices." The IAEA was designated as the international instutitional mechanism to carry out the verification function. The Treaty assures NNWS parties that research, development and production directed toward peaceful means would not be constrained by the Treaty and that all parties would strive for the fullest possible exchange of equipment, materials and scientific and technical information consistent with the undertakings.

There are additional features to the Treaty such as undertakings by the Nuclear Weapons States (NWS) to work toward cessation of the nuclear arms race.

IV. THE TREATY FOR THE PROHIBITION OF NUCLEAR WEAPONS IN LATIN AMERICA

This Treaty, also known as the Treaty of Tlatelolco, was concluded in 1967. Although not equivalent in all respects to the NPT, it contains many strong provisions that support non-proliferation. Because it requires IAEA full-scope safeguards, includes a pledge for use of nuclear materials and facilities for peaceful purposes only and prohibits the presence, production, acquisition, or testing of nuclear weapons within a signatory's territory, adherence to the Treaty is accepted by supplier nations in a manner similar to that for an NPT party.

V. THE CONVENTION ON THE PHYSICAL PROTECTION OF NUCLEAR MATERIAL

Negotiation of an international convention on the physical protection of nuclear material was concluded under IAEA auspices in October 1979. Representatives of 58 States participated in the drafting. The U.S. became a signatory on March 5, 1980, when the Convention was opened for signature.

The Convention addresses the need for the physical protection of nuclear material while in international transport and while in domestic use, storage and transport. It specifies levels of protection, procedures for pursuit and recovery of material, and arrangements for apprehension of offenders. These measures, including the exchange of information on materials in transit, will further assist in the implementation of safeguards.

VI. NON-PROLIFERATION, NON-DIVERSION AND SAFEGUARDS TODAY

Exploitation of nuclear energy for peaceful uses, while constraining proliferation and diversion of special nuclear materials, is dependent upon a strongly and universally supported International Atomic Energy Agency, adherence to the Non-Proliferation Treaty and/or the Treaty for the Prohibition of Nuclear Weapons in Latin America, and acceptability of Nuclear Suppliers' Agreements. Additionally, where direct U.S. cooperation with another nation is involved, there is the Atomic Energy Act of 1954, as amended, that requires international agreements for cooperation, and the Nuclear Non-Proliferation Act of 1978.

In the mid-1970s, there began a re-examination of the policies and practices underlying the non-proliferation regime. It was triggered in part by the Indian nuclear explosion of 1974 and in part by the concern that, with the worldwide growth of nuclear power programs and the assumed accompanying reprocessing of spent fuel, large quantities of plutonium would be readily accessible. Many believe that it is only a short step from available plutonium to a nuclear weapon, that is, that the technical work necessary for design and fabrication is easily accomplished. Doubts were raised that the then existing safeguards system could provide the "timely warning" necessary for diplomatic activity to take place.

These beliefs, the technical one that a nuclear explosive can be made quickly, once the separated plutonium is available, and the political one that appropriate counteraction could not be accomplished on a sufficiently short time scale, gave rise to a conclusion that there exists an unacceptable risk of proliferation even with the best safeguards system. This line of reasoning led to a position that the breeder, reprocessing and the so-called plutonium economy should, at a minimum, be deferred while re-examination took place. As you know, there are differing views on this subject and the International Nuclear Fuel Cycle Evaluation (INFCE) was organized in 1977 to study technically the various elements including alternatives.

VII. THE INTERNATIONAL NUCLEAR FUEL CYCLE EVALUATION

There is no question but that INFCE was a most valuable forum that brought parties together to study technically the many aspects of nuclear power development and utilization that could have an impact on nuclear weapons proliferation. It was a useful consciousness-raising exercise for governments and for the public. It will provide governments with extensive information that should assist them in their own decision making and in pointing the way to strengthening the non-proliferation regime.

Let me highlight a number of points, taken from the report, that have or will have a bearing on safeguards-related activities.

1. Nuclear power has and will have continuing value for many national economies. At the same time, there are proliferation risks associated with nuclear power as well as measures that can and should be taken to make such risks more tolerable and manageable.

2. Proliferation is basically a political matter; if a nation elects to develop nuclear explosives, it can do so without misusing civilian nuclear power facilities.

3. Since facilities, however, can be misused, it is important to plan future fuel cycles with careful attention to proliferation risks. No technical solution was identified that will eliminate such risks, but several major positive factors that will be useful in future planning were identified.

4. Substantial risks are associated with weapons-usable materials and the technologies that can produce them. New protective measures, including but not limited to improved safeguards, will be required to cope with fuel cycles involving ready access to significant amounts of weapons-usable materials.

5. While reprocessing is preferred by some nations as the way to deal with spent fuel, other choices are feasible, for example, spent fuel storage and terminal disposal without reprocessing.

6. For economic reasons, when reprocessing plants are built they, like enrichment plants, should be large in scale. Scale is also an important consideration for non-proliferation reasons.

7. The economic advantage of plutonium recycle in light water reactors will at best be small.

8. Effective international safeguards are an essential feature of nuclear fuel cycle facilities. The special need to apply effective safeguards, particularly for the sensitive fuel cycle steps involving enrichment, reprocessing, and fabrication of fuel using plutonium or highly enriched uranium, was recognized. Inclusion of safeguards planning at the earliest stages of plant design is called for. The importance of giving high priority to the testing and optimization of new improved safeguards methods for sensitive fuel cycle steps was emphasized.

9. Constraints that now apply to reprocessing and to separated plutonium need to be reinforced by other protective mechanisms, for example, placing excess plutonium under international oversight.

10. A combination of new safeguards, technical and institutional measures constitutes a promising approach to reducing potential proliferation risks. It will take major efforts by many nations to implement such measures, for example, a new multinational venture, by the time they are needed to deal adequately with the proliferation risks which are inherent in such sensitive facilities as reprocessing and enrichment plants.

The above enumeration is not intended to be all inclusive. It does emphasize the need for greater attention to sensitive technologies and processes and the handling of sensitive materials. It emphasizes the importance of nuclear materials accounting, containment and surveillance, and it emphasizes the importance of institutional mechanisms, the IAEA, the various Treaties and the future potential international or multinational arrangements.

VIII. TRENDS

The world of energy has been undergoing some drastic changes in the past five years, even more changes can be anticipated for the decade of the 1980s. Energy is no longer the relatively cheap, easily available commodity that it once was for many nations of the world. A number of "concerns" are now influencing national and international energy planning. For example:

Concern for limiting the use, especially for export, of a nation's in-the-ground resources--prospect of limited national oil resources.

Concern for public health--pollution from burning coal and oil, nuclear radiation from power-related activities.

Concern for the environment--changes because of new hydro locations, acid rain from fossil plants, ocean spills of oil, nuclear waste management.

Concern for national security--availability of primary energy resources, nuclear proliferation.

Concern for political stability--adequacy of energy resources, stability of world commerce.

The effects of OPEC pricing of petroleum are well-known to you. The concerns expressed above have slowed down the rapid introduction of other supply alternatives so that all energy prices have escalated dramatically. The most striking consequence has been the adoption of an energy conservation ethic, in order, first, to realize real savings, and second, for the electric economy, to buy time before new generating capacity must be added.

The U.S. National Academy of Sciences recently completed a study (CONAES) of nuclear and alternative energy options for the future. There were five general observations offered; however, the one most directly of interest to this audience is that which focussed on the desirability of a balanced combination of coal and nuclear fission as the only large-scale intermediate-term option for electricity generation. This study addressed U.S. needs; however, with a priority on oil for transportation and petrochemicals and, for many nations, the lack of indigenous coal, there could well be a shift by such nations to a strong preference for nuclear. One cannot ignore a nation's present status, for example, its per capita energy consumption and opportunities for growth. The problems, though different, exist for both industrialized and developing nations.

The call for nuclear power is clearly there; the problem for us is to make it acceptable. The IAEA is playing a major role through its programs of education and training and its health and safety guidelines. At the same time, its role in safeguards is necessary in assuring a peaceful uses-only utilization, also an element of public acceptance.

Thermal reactor systems are in operation today and will continue to be built for the indefinite future. There are safeguards requirements for elements of the fuel cycle, front-end requirements for enrichment and fuel element fabrication and back-end requirements for spent fuel storage, reprocessing and waste management. The drive for resource conservation will make the breeder a most likely option for the future; the questions are when and where.

But this optimistic picture of a nuclear power future will take place only if nations have the assurance that it can take place without undue risk to health and to national security. We need the combined efforts--technical, institutional and political--to achieve the objective.

IX. EMPHASIS ON SAFEGUARDS

Nuclear materials accountability for safeguards purposes has been required from the very beginning of international nuclear cooperation. Control and surveillance are being used to augment materials accountability. The emphasis on safeguards has increased with time, in part because of the expanding nuclear economy and in part because of the hope and desire that technical safeguards themselves would be sufficient to prevent proliferation. Improvements have been made and are being made. It is obvious, however, that the final decision of whether or not a violation has occurred will be a combination of judgments, the one derived from the application of safeguards being extremely important.

The institutions and instruments that support non-proliferation are dependent upon the effective application of safeguards.

- o The NPT requires applications of safeguards and assigns the international verification role to the IAEA.
- o The suppliers' agreements require IAEA safeguards as a condition for export.
- o The U.S. Nuclear Non-Proliferation Act of 1978 emphasizes the role of safeguards and requires the U.S. government to assist in improving international safeguards.
- o The INFCE report reinforces the requirement for improved safeguards.

In this day and age of looking to science and technology to cure the world's ills, leaders look to the safeguards system to assure a non-diversion, non-proliferation nuclear world. Although the safeguards system goes a long way, it will never be able to do the job alone. At the same time, other mechanisms cannot do the job without safeguards on which they can build. In short, good safeguards are absolutely necessary.

International safeguards as one element in the overall system builds on national (domestic) safeguards. The international system was never intended to do the whole job; it is intended to verify that the domestic system is working and that an internationally verified conclusion of non-diversion can be accepted with a high degree of confidence.

Thus the IAEA's findings can be no better than the facts upon which they are based, namely, those derived from the national system. In my view, there is opportunity for cooperation even when the IAEA must assume an adversary role. It is in the State's best interest to maintain a good safeguards system and to implement it effectively with accuracy and timeliness. It is in the State's interest to cooperate with the IAEA in making the verification process simple and effective. If the State's own system is ineffective and incomplete, the IAEA will have great difficulty in arriving at a conclusion favorable to the State. If the State has a practice of making the verification process difficult, which it can do in any number of ways, the IAEA may not be able to reach a conclusion of "no diversion" because of lack of supporting information.

X. SUMMARY

It is just over a quarter of a century since President Eisenhower proposed that there be international cooperation in the peaceful use of nuclear energy under controls to assure that this cooperation would not be diverted to military uses. We are in the tenth year of the coming into force of the Non-Proliferation Treaty. The utilization of safeguards as a measure to ensure no diversion to a military purpose was originally directed to national diversion. With the advent of terrorism, greater attention is being given to sub-national activities that may have objectives other than a national military use. Containment and surveillance, along with greater physical protection of sensitive materials and plants, have been added to nuclear materials accounting as measures to prevent as well as to detect unauthorized use.

The success of safeguards is a combination of technical capability, political will and international cooperation. The granting of inspection rights to the IAEA for a nation's total civil nuclear program is a strong indication of a country's concern and an indication of its willingness to cooperate with others in limiting further proliferation that might result from peaceful pursuits. The more effective and the less obtrusive we can make the implementation of safeguards, the easier it will be to overcome political difficulties.

One cannot overlook costs. There are many similarities between safeguards, safety and environmental controls. They are all of a regulatory nature, imposed upon the operators to provide a benefit to society. The advocates will argue that one should do everything possible to protect the public or the environment without regard to cost. This is an unrealistic objective; zero risk is impossible, and certainly one can reach the point of diminishing returns, that is, a rapid increase in costs to achieve a further reduction in an already low risk. The decision of how much is enough is a societal one that is made through the political process.

If we ask the question, could the IAEA and the NPT be created today, the answer is probably not. The existing international institutions and instruments were established at a most propitious time. They do exist, they have made possible bringing the benefits of atomic energy to a far larger fraction of the world's population than otherwise would have been possible. We should be thankful to those who had the foresight and perseverance to give them the strength they have today. The experience gained gives us insight as to ways and means for improvements--increased benefits with increased assurance of no diversion. We must build on our present base of technology, of institutions and of political will.

An effective State system of nuclear materials accountability and control for safeguards purposes provides the basis on which the international system of verification can take place. A weak or questionable safeguards system will not provide the public or nations with the confidence necessary to allow nuclear energy to be used for its greatest benefits to society. It is up to us to foster the technical, institutional and political action necessary to provide that confidence.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #4: DESCRIPTION OF A STATE SYSTEM AND ITS REQUIREMENTS

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Tuesday, May 27, 1980
4:00 p.m.

BIOGRAPHY

Education: US Naval Academy - Engineering - B.S.; US Naval Post Graduate School - Physics - M.S.; Stanford Business School - Management Accounting - MBA

Present Position: Chief, Material Control & Accountability Licensing Branch, US NRC, Washington, DC

Present Duties: Responsible for Review and Approval of Material Control & Accounting Plans for Licensed Fuel Facilities in US.

Past Positions: Four years experience as a Safeguards Inspector for US facilities. Fourteen years as a US naval officer in the Nuclear Submarine Program.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #4: DESCRIPTION OF A STATE SYSTEM AND ITS REQUIREMENTS

This lecture will trace the history of the development of the US Domestic Safeguards System over the past 25 years. This development will include a discussion of the changing needs for the State Safeguards program as well as a discussion of the interrelated roles of material accounting, material control, and physical protection systems as they have been developed to meet safeguards needs. While the lecture will stress the development of the US Domestic System, it will also include a discussion of its compatability with International safeguards requirements as well as modifications that are being made to the domestic system in order to accommodate the implementation of IAEA safeguards in the United States.

After the session, participants will be able to

1. Understand the need for a State System.

2. Understand the roles of Accountability, Material Control, Physical Protection.

3. Understand the similarities as well as the differences between domestic and international systems.

SESSION 4: DESCRIPTION OF A STATE SYSTEM AND ITS REQUIREMENTS

James G. Partlow
U.S.N.R.C.

I. INTRODUCTION

During the next two weeks you will be exposed to lectures, discussions, and other training sessions designed to improve and expand your knowledge of systems and methods that can be used to establish a national system of accountability and control over special nuclear materials---an SSAC.

First, I would like to congratulate you upon your selection to attend this course. In addition to demonstrating your countries' interest in pursuing this important program, your presence here indicates that you have been judged to possess the combination of technical skills, common sense, and motivation that are necessary to use and expand on what you learn here in improving the SSAC in your own country.

My primary objective during this first day of the course is to emphasize the fact that the establishment of a strong SSAC is essential to the effectiveness of the IAEA in fulfilling its international safeguards role; that individual states, as signers of the Non-Proliferation Treaty, have an obligation to establish SSACs in support of international safeguards, and finally, that the establishment of a strong SSAC, as an integral part of a comprehensive overall domestic safeguards program, is in the best interest of the state in protecting the health and safety of its citizens.

In discussing the need for a strong SSAC for both domestic and international purposes, we will also examine the general features and requirements of a state safeguards system and introduce its basic elements of Material Accounting, Material Control, and Physical Protection.

II. THE NEED FOR NUCLEAR MATERIALS SAFEGUARDS AS A PRUDENT DOMESTIC PROGRAM

A. Background

The development of the nuclear industry as part of a nation's energy supply system presents a potential for increasing the risk of harm to the general public from: (1) theft or diversion of special nuclear material (SNM) which can be fabricated into a nuclear explosive device or used for dispersal of radioactivity, and (2) sabotage of nuclear material or facilities leading to dispersal of radioactivity. Actions of either type may appeal to dangerous elements of society. Such elements could include criminals, motivated by personal gain (from sale of SNM or by extortion); extremists, exerting pressure for socio-political or economic change; and disoriented persons seeking revenge for some perceived wrong.

Groups that could in theory take malevolent action against nuclear plants or materials occupy a wide spectrum. For purposes of establishing safeguards controls, two categories of groups are considered most likely to constitute a threat in the future. These are: (1) a small group of individuals possessing the highest motivation and skill needed to achieve their goals, including a willingness to receive and inflict casualties, and equipped with automatic weapons, and (2) disgruntled employees with access to nuclear fuel industry operations and thus capable of acting covertly.

The nature of special nuclear material, with its potentially high risk to the public, demands that proper safeguards precautions be observed. The general world-wide increase in terrorism has heightened concern over the possibility of attempted sabotage or seizure of materials for illicit use. Such events have in turn been widely publicized in the media with the result that public awareness and concern is growing because of this increased publicity.

For domestic purposes, safeguards are defined as those measures employed to deter, detect, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion, and (2) the sabotage of nuclear materials and facilities. The domestic safeguards program has the general objective of providing a level of protection against such acts that will insure against significant increase in the overall risk of death, injury, and property damage to the public from other causes beyond the control of the individual. To be acceptable, safeguards must take realistic account of the risks involved and of burdens on the public in terms of civil liberties, institutional, economic, and environmental impacts.

In order to deter, detect, prevent, and respond to sub-national attempts at theft of nuclear material or sabotage of facilities, an organized, national program of materials accounting and control and physical protection is needed. While these are terms that are generally used to describe the basic components of the U.S. domestic safeguards program, many aspects of these programs (particularly in the area of material control and accounting) are similar and complimentary to international safeguards programs that are generally considered to be a part of a State's System of Accounting and Control.

B. Definitions

At this point, I would like to introduce some general definition of the terms Material Control, Material Accounting, and Physical Protection, and discuss the roles that they play in the overall safeguards program. In the U.S. domestic program, we generally define these terms as follows:

Material Control is that part of the safeguards program encompassing management and process controls to (1) assign and exercise responsibility for nuclear material, (2) maintain vigilance over the material, (3) govern its internal movement, location, and utilization, and (4) monitor the inventory and process status of all nuclear material.

Material Accounting is that part of the safeguards program encompassing the procedures and systems to (1) perform nuclear material measurements, (2) maintain records, (3) provide reports, and (4) perform data analysis to account for nuclear material.

Physical Protection is that part of the safeguards program encompassing the equipment, procedures, and physical controls to (1) protect nuclear materials from theft or diversion through the use of access and egress controls and physical barriers, (2) detect attempts at theft or diversion through the use of surveillance measures and alarm systems, and (3) respond to attempts at theft or diversion through the use of on-site security personnel and off-site law enforcement assistance.

In a very general sense, one might look at material control and material accounting as those measures that are applied to ascertain and manage the status of nuclear materials, while physical protection measures are those that are applied to ascertain and manage the status of people.

Given the domestic safeguards functions of deterrence, detection, prevention, and response to the theft of nuclear materials, let us consider the role that material control and material accounting programs should play in making the overall system work.

Deterrence is the safeguards function that incorporates measures intended to discourage a potential adversary from attempting a malevolent act. Prevention is the safeguards function that consists of measures to impede or stop an adversary from successfully completing a malevolent act or successfully perpetrating a hoax. Response is the safeguards function that provides for loss Detection and assessment and for a predetermined course of action in response to an actual or alleged theft.

One other function, Assurance, can be inferred from the safeguards objective statements. Assurance is the safeguards function that incorporates measures to satisfy the state and the public that the safeguards program is in place, that it can respond effectively to a threat or an attempted malevolent act, and that nuclear materials are present in assigned locations and accounted for.

C. Rules of Material Control and Material Accounting Systems

Having structured the safeguards program into these major functions, the roles that material control and material accounting systems should perform can be described with respect to their contributions to these functions.

The material control system should contribute to deterrence by providing a means of readily detecting unauthorized removals of SNM, and tracing and identifying suspects, thus deterring those who fear exposure. By maintaining continuous vigilance over material, monitoring process operations, and establishing cross-checks over material movements, material transactions, and administrative controls, the material control system can provide early warning of attempts at theft or diversion. Full use of process monitoring information can provide additional safeguards alarms and can improve data analysis capabilities. Thus, the material control system should contribute to the prevention function by providing timely information to improve material loss alarm responsiveness, leading to the interruption of attempts to steal or divert material. The material control system, by continuous monitoring and vigilance, should play a major response role in the rapid discovery of a loss of material. Material control should also play an important short-term assurance role by providing continuous indication of effective system operation and by confirming material status between physical inventories.

The material accounting system should contribute to deterrence by providing an after-the-fact detection capability for significant material loss and by discouraging those who desire anonymity after committing a theft. In the case of a hoax, the material accounting system plays an important prevention role in combating the alleged theft by providing records of material quantities and locations to assist in the verification of plant holdings. With respect to the response function, the material accounting system, especially the records, can contribute in a major way to after-the-fact loss detection, to the precise assessment of losses or alleged losses, and to the identification of suspects. However, it is in the area of assurance that material accounting makes its greatest contribution to safeguards. The primary role of material accounting is to provide long-term assurance, through records of holdings verified by physical inventories, that material is present in assigned locations and in correct amounts. In addition, shipper-receiver comparisons provide assurance that material has not been lost or stolen in-transit and that overstatements of a plant's shipments or understatements of receipts are not being used to disguise a material loss or theft.

III. THE NEED FOR A STRONG SSAC IN SUPPORT OF INTERNATIONAL SAFEGUARDS.

A. Background

The basic objective of international safeguards, as administered by the IAEA, is the timely detection of diversion of significant quantities of nuclear materials. In the international context of non-proliferation of nuclear weapons, the word "diversion" (as opposed to theft by persons of subnational organizations) is recognized to mean actions by a state to remove materials from commercial, peaceful applications and apply them to use in a weapon or nuclear explosive device. Given the growth in the peaceful uses of nuclear materials throughout the world, both in terms of the quantities of materials utilized as well as the number of nations utilizing nuclear power, the IAEA objective of early detection of diversion represents a significant challenge that is growing with each passing year. Short of utilizing massive financial and personnel resources from the member nations to continuously oversee and directly measure and account for all aspects of the global use of nuclear materials, the IAEA system must be dependent upon the positive actions and cooperation of participating states if it is to fulfill its objective without unreasonable costs. A nationally administered and supported State System of Accounting and control, leading to the implementation and maintenance of effective accounting and control procedures by each facility operator can and must provide the basic framework and substance of a system that will allow the IAEA to be successful in its objective in a world of limited financial resources and qualified personnel. When a structured, effective program of accountability has been established at the facility level, and when that program is administered and managed at the State level for all facilities in a comparable manner, only then can the IAEA program of periodic inspections, records examination, material verification, data analysis, and surveillance measures be effective in confidently overseeing peaceful nuclear activities. Each nation which participates in and supports international safeguards cooperation seeks and expects confidence that the IAEA can and is doing its job. As you begin your studies here today, the primary thought which I want to leave with you is this: our collective confidence in the IAEA system depends heavily upon the actions of each participating nation in establishing and maintaining a State System of Accounting and Control which supports and enhances IAEA safeguards.

B. Major SSAC Components that Support International Safeguards

Let us now briefly look at the major SSAC components which each state is expected to maintain in support of international safeguards. These overall components include:

- A system of National Regulations that incorporates into law the safeguards programs and procedures to be followed by facility operators.
- A system of Licensing to establish authorized uses and quantities of nuclear materials, and to incorporate a mechanism for the state review and approval of local procedures (prepared by individual facilities) to be followed

in compliance with the regulations.

- A program of controlling and maintaining Compliance to the regulations and license conditions through state inspections.
- The establishment of an Information System to be used in maintaining knowledge of the status of nuclear materials within the state.
- A program of national Technical Support to provide training programs, assistance to facility operators, and research and development programs for improving material accounting and control in the state's facilities.

C. Accounting and Control

The IAEA's Information Circular #153 contains a summary of the accounting and control measures that should be included in the SSAC's program of regulations and licensing reviews. This document requires that a facility's accounting and control procedures be based upon a structure of Material Balance Areas and should include the following elements:

- A measurement system for the determination of the quantities of nuclear material received, produced, shipped, lost or otherwise removed from inventory, and the quantities on inventory;
- The evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty;
- Procedures for identifying, reviewing and evaluating differences in shipper/receiver measurements;
- Procedure for taking a physical inventory;
- Procedures for the evaluation of accumulations of unmeasured

inventory and unmeasured losses;

- A system of records and reports showing, for each material balance area, the inventory of nuclear material and the changes in that inventory including receipts into and transfers out of the material balance area;
- Provisions to ensure that the accounting procedures and arrangments are being operated correctly; and
- Procedures for the provision of reports to the Agency.

D. Containment and Surveillance

In addition to the above basic elements that constitute a program of material accounting and control, there are two other general elements to an SSAC---the elements of Containment and Surveillance. These measures are necessary in order to enable the IAEA, as part of its material control function, to monitor flows, to confirm the identity of stored material, and in general to indicate when material present in a material balance area or facility is removed without appropriate accounting action.

As used in safeguards, the term containment refers to physical barriers, fences, transport containers, processing tanks, etc., that in some way physically restrict or control the movement of nuclear materials. Containment measures are used by plant operators for a number of reasons, e.g., physical protection of material, safety of personnel, or convenience of operations procedures. In general, containment measures are not provided specifically for international safeguards purposes, but their existence in a facility will simplify the application of surveillance devices by the IAEA. As a simple example, it is clearly easier to observe the movements of nuclear materials from a building with one exit than from a building with ten exits. The concept of containment may help in defining material balance areas for accounting purposes but the physical boundaries that confine nuclear material within a facility do not always correspond with boundaries of material accountancy. In other words, the existence of containment barriers is not decisive in delineating such MBA's.

Surveillance means instrumental or human observation to indicate or detect the movement of nuclear material. Surveillance instruments and devices indicate that either no nuclear material has left a certain location or that it has left only via legitimate routes. In their role of independently verifying the effectiveness of containment, surveillance instruments thus indicate whether containment of nuclear material in a location was broken or not during a certain period.

Surveillance as applied or required by the IAEA may include, for example, observation by responsible personnel, the use of tamper-resistant instrumentation or other equipment, seals to ensure that the integrity of containment has not been breached; doorway monitors to detect removal of nuclear material, closed circuit television surveillance equipment in combination with a video recorder, or film cameras, to take and store pictures for subsequent review.

In IAEA safeguards procedures, surveillance is recognized as an important measure to complement nuclear material accountancy. Surveillance is greatly assisted by the provision of containment measures but in using surveillance devices for IAEA safeguards purposes it is recognized that:

- Their installation must be agreed in detail with the plant operator taking due cognizance of any legal, personnel or operational requirements;
- They are designed to give information relating only to the movements of materials, to reactor operational history, etc., for IAEA safeguards purposes; and
- They are not installed for the direct observation or monitoring of plant operator's staff.

IV. OBJECTIVES OF AN SSAC RELATIVE TO INTERNATIONAL AND DOMESTIC SAFEGUARDS

Before going further, let us review the safeguards elements that we have introduced so far in describing an SSAC. Keeping in mind the idea that an effective SSAC is needed for both international and domestic purposes, we have addressed the following points.

For Both Domestic and International Safeguards: The SSAC should include programs for Regulations, Licensing, Compliance, Information systems, and Technical Support.

For Domestic Safeguards: In order to deter, detect, prevent and respond to the theft of nuclear material by persons or sub-national groups, an SSAC's regulations (perhaps more appropriately called a State System of Safeguards in this case) should make provisions for requiring material accounting and control measures and a physical security system.

<u>For International Safeguards</u>: In order to support the IAEA objective of detecting significant diversion at the national level, an SSAC's regulations should make provisions for requiring material accounting and control measures, plus containment and surveillance measures.

What are the differences and similarities between international and domestic objectives for an SSAC? In order to answer this question, we need to take a closer look at the domestic safeguards program. The threat of theft of material by persons or groups might conceivably come in one of two forms: convertly by plant employees or other persons who are routinely present within the facility, or overtly by external attack (either with or without the assistance of persons within the plant). Rather clearly, protection against the external, perhaps violent, assault is the job of a physical protection system, with little contribution forthcoming from the accounting and control systems in preventing a theft. So, while the idea of a physical protection system consisting of armed guards, penetration-resistant barriers, etc., is certainly a necessary and appropriate part of a domestic safeguards system, such measures would not be necessary solely for the purpose of supporting international safeguards.

Concerning the threat of theft by plant insiders, other measures that are also normally described as a part of the physical protection system, play a major role in deterring, detecting, and preventing insider theft. In the U.S. domestic system, the physical security system includes such measures as control of personnel access to SNM areas, personnel exit searches, surveillance of personnel and operating areas, and operation of electronic intrusion alarm system. Other domestic measures that we consider to be a part of physical protection include the use of secure storage areas, and the requirements that nuclear materials be placed in secure storage when not actually undergoing processing.

By now, you can see that these measures to protect against insider theft, that are called physical protection measures in the U.S. domestic system, are in fact very similar to those measures that are known as containment and surveillance in the IAEA international system. While the incorporation of such programs into the SSAC has direct application for domestic safeguards purposes, their international safeguards role is to support IAEA safeguards in providing mechanisms to enhance surveillance by the international authority.

In summary, many of the concepts that are often termed as physical protection measures in a domestic system are identical to those measures that are known as containment and surveillance in international safeguards.

V. THE SAFEGUARDS SYSTEM IN THE U.S. PRIVATE SECTOR

A. Background

As a final segment of this paper, I would like to very briefly describe the U.S. private sector safeguards system that we have today. But first, some background and history might be appropriate.

Prior to 1954, all special nuclear materials in the United States were owned by the Federal Government. Only relatively small quantities of these materials existed at that time and they were protected largely in the interest of maintaining nuclear secrecy. The development of a private nuclear industry began in 1954, when nuclear materials were made available to private individuals and organizations for peaceful uses. These materials were still owned by the U.S. Government and it was not until 1964 that Congress enacted legislation authorizing private ownership of special nuclear materials.

In mid 1960's it became apparent that development of economically attractive nuclear commercial applications would result in increasing quantities of nuclear material in the private sector. Furthermore, these increased quantities of materials, together with the accompanying growth of nuclear fuel facilities and the spread of nuclear technology, could contribute to increased opportunities for malevolent acts involving nuclear materials unless appropriate safeguard measures were implemented. Accordingly, in July 1966, the U.S. Atomic Energy Commission (AEC) established an Advisory Panel headed by R. F. Lumb, charged to conduct an independent review and appraisal of U.S. safeguard policies and procedures.

The work of that panel was reported in early 1967 and had a significant effect on U.S. safeguards policy. Previously, the scope of safeguards policy was limited, by and large, to material accountability. Prior to this time, it has been assumed that adequate control and accountability of nuclear materials would be maintained by commercial facilities because of the intrinsic value of the material. But the Lumb report raised the issue of safeguards against sub-national threats posed by criminals and terrorists. Thus, the report, reinforced by the social turmoil and terrorism that had erupted toward the end of the 1960s set the stage for greatly increased attention to the physical security of nuclear materials held in the private sector.

During the ensuing three year period between 1967 and 1970, the Atomic Energy Commission issued regulations requiring more comprehensive material control and accounting programs and establishing requirements for the physical protection of significant quantities of nuclear materials, both in transit and at fixed sites. During this same period, the U.S. domestic safeguards program began to develop the major components of an SSAC which were discussed earlier; a system of national regulations, licensing, compliance oversight, information systems, and technical support.

B. Present and Furture Status

Today the U.S. Nuclear Regulatory Commission (NRC) is responsible for administering the safeguards program for commercial facilities. For safeguards, as well as for the other aspects of nuclear safety, the NRC has developed major program offices to administer each of the basic components. The Directors of these offices report directly to the NRC's Commissioners through an Executive Director for Operations. Safeguards regulations are developed by the Office of Standards Development. The licensing process is conducted by the Office of

Nuclear Material Safety and Safeguards. Compliance inspections are conducted by the Office of Inspection and Enforcement, that includes five regional offices in addition to the Washington headquarters. Technical support and guidance is provided by the Offices of Nuclear Regulatory Research and Standards Development. Additionally, technical support as well as the administration of a national information system for nuclear materials is provided by the U. S. Department of Energy in coordination with the major NRC program offices.

Although the development of a comprehensive U.S. safeguards program (our SSAC) began well over ten years ago, the program is still developing and changing. Today, we are seeking to establish a graded system of safeguards. By "graded" safeguards, I mean the application of an appropriate level of protection and an appropriate mix of physical protection and material accounting and control that recognizes the differences in the potential mis-use of source materials, slightly enriched uranium, highly enriched uranium, and plutonium, both at fixed sites and during transit.

In addition to our continuing efforts to improve the domestic safeguards program, the U.S. is also now preparing to implement IAEA safeguards at eligible facilities in both the commercial and government sectors of the nuclear industry. In anticipation of the ratification of the treaty by the U.S. Senate this year, the NRC is now completing a new set of national regulations that sets out the rules for implementation of IAEA safeguards by facility operators. Accounting and control measures, mainly as specified in Facility Attachments, will be incorporated as conditions of the license which is required for each commercial holder of nuclear materials. Operator compliance with procedures that support IAEA safeguards will be monitored by the Office of Inspection and Enforcement. Whenever possible, NRC safeguards inspectors will accompany the IAEA during these inspections. Our national nuclear materials information system is now being modified to accomodate the reporting of accounting information to the IAEA. Technical support for facility operators who will be subject to IAEA safeguards is and will continue to be provided through site visits by NRC headquarters personnel and through our regular program of distribution of technical reports and guidance.

In summary, the U.S. experience to date has been that a well developed State System of Accounting and Control, in addition to its original purpose for domestic safeguards, is serving as an excellent foundation upon which a program of international safeguards support can be efficiently and effectively added. I will leave you with that thought as you begin your studies here.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #5: DOMESTIC SAFEGUARDS: THREAT ANALYSIS AND RESPONSE CAPABILITIES

SPEAKER: Dr. Brian Jenkins

RAND Corporation
Santa Monica, California, USA

Tuesday, May 27, 1980
8:30 p.m.

BIOGRAPHY

Education: University of California at Los Angeles (UCLA), completing dissertation in history; UCLA, M.A., History (1964); UCLA, B.A., Fine Arts (1962).

Present Position: Associate Head, Social Science Department, The Rand Corporation; Program Director, Security and Subnational Conflict.

Mr. Jenkins is the author of numerous publications. Among them. "The Potential for Nuclear Terrorism," "The Consequences of Nuclear Terrorism," "Attributes of Potential Criminal Adversaries of U.S. Nuclear Programs," "Will Terrorists Go Nuclear?" "Motivations and Possible Actions of Potential Criminal Adversaries of U.S. Nuclear Programs," and a recently completed book, "The Fall of South Vietnam."

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #5: DOMESTIC SAFEGUARDS: THREAT ANALYSIS AND RESPONSE CAPABILITIES

The possibility that terrorists or other criminals might attempt to sabotage nuclear facilities, obtain nuclear material, or create alarming nuclear hoaxes, has caused increasing concern and creates special problems for the security of nuclear programs. Recent incidents involving nuclear facilities or material, which suggest that the threat is not entirely hypothetical, are discussed. The methodological problems and basic approaches to threat analysis are then described with the results obtained from recent research. The implications for security are examined in terms of response capabilities, contingency planning, and effective handling of threats or incidents involving nuclear facilities and programs.

After the session, participants will be able to

1. Have an appreciation of the elements of threat analysis as applicable to individual national environments.

2. Outline the requirements of an effective government response to actions or threats directed against nuclear facilities and programs.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 5: DOMESTIC SAFEGUARDS: THREAT ANALYSIS AND RESPONSE CAPABILITIES

Brian Jenkins
Rand Corporation

I. INTRODUCTION

The possibility that terrorists or other kinds of criminals might attempt to seize or sabotage a nuclear facility, steal nuclear materials for the purposes of sale, extortion, or use in a clandestinely-fabricated nuclear device, or carry out other criminal activities in the nuclear domain has created special problems for the security of nuclear programs. For many years now, Sandia Laboratories, at the direction of the Department of Energy, has played a leading role in developing and testing new measures of protection. In 1975, Sandia asked The Rand Corporation to assist it in analyzing the potential threat to U.S. nuclear programs. (The Rand Corporation is an independent and nonprofit corporation, headquartered in Santa Monica, California. It conducts research on matters affecting the public interest--questions involving U.S. strategic and foreign policy, urban development, education, health, energy, and other areas. For the past eight years, it also has been engaged in research on international terrorism and subnational conflict.)

II. SCOPE OF PROBLEM

A. Task Description

Our task has been to describe the potential criminal adversary, or rather the spectrum of potential adversaries, who conceivably might carry out malevolent criminal actions against nuclear programs and facilities in the United States. In the following discussion, I will describe some of the unique methodological problems in carrying out this task and our solutions to these problems. I will then briefly summarize some of the conclusions reached in our study, and the implication these have for security.

B. Definitions

We use the term "nuclear programs and facilities" in its broadest sense, to include weapon fabrication facilities, civilian nuclear energy facilities, other facilities in the nuclear fuel cycle, nuclear research facilities that fabricate fuel for naval reactors, and all related transport of nuclear material. The term "criminal adversary" refers to those who might carry out malevolent criminal action against a nuclear target or an action involving nuclear material or weapons. We exclude from this category legitimate acts of protest and even minor delinquencies such as trespassing when these are not part of a more serious action.

C. Types of Crimes

We are most concerned with crimes that may cause significant damage or disruption, and especially with those crimes that may directly or indirectly imperil public safety. We include among these attack, seizure, or sabotage of a nuclear facility; threats against nuclear facility personnel or their kidnapping or assassination; theft or diversion of nuclear material; deliberate release or radioactivity; theft or detonation of a nuclear weapon; construction of an improvised nuclear device; and extortion involving nuclear materials or weapons.

D. Material and Operational Capabilities of the Adversary

The initial phase of our research focused on the material and operational capabilities likely to be displayed by various categories of potential nuclear adversaries. We examined such issues as the number of attackers, their likely armaments, tools, and transport; their possible modes of operation, and other attributes such as their level of technical skill, the importance of and their ability to recruit inside assistance, and their willingness to risk capture or death.

E. Few Serious Occurrences

The principal methodological problem in conducting such research is that there have not been a great number of serious actions directed against U.S. nuclear facilities. No nuclear installations in the United States have been attacked, seized, or sabotaged in a way that caused the release of radioactivity. No nuclear weapons have been stolen or illegally detonated. No special nuclear materials have been diverted or taken by force from installations or while in transit and used for blackmail or made into bombs. And no radioactive matter has been maliciously dispersed so that public safety was endangered.

F. Specific Occurrences

A number of bomb threats have been telephoned to nuclear facilities, a now common occurence in both government and industry. A number of threats to use nuclear material have proved on investigation to be hoaxes. Minor sabotage has been carried out in a handful of cases. In one incident, a minute quantity of SNM was removed from a reprocessing facility. Although a certain amount of nuclear material is unaccounted for, there is no available evidence that it was stolen or diverted to weapons use.

Outside of the United States there have been a few incidents of more serious potential consequences. Urban guerrillas briefly seized control of a nuclear facility under construction in Argentina. Political extremists on several occasions have attempted to sabotage or have sabotaged operating reactors or reactors under construction in Europe. Most of these incidents occurred after we began our study.

G. Lack of Statistics

Ironically, the relative freedom from serious nuclear incidents in this country and abroad presented a problem for the researchers. Lacking an adequate sample of nuclear incidents from which we might build a profile of the adversaries, we expanded our study to include actual crimes outside of the nuclear domain that are in some way analogous to possible but uncommitted nuclear crimes.

III. STATISTICS DERIVED FROM TERRORISM AND CONVENTIONAL CRIME

A. Analysis of Conventional Crimes and Terrorism Incidents

Several hundred cases of conventional crimes were analyzed. These included sophisticated burglaries, major armed robberies, and industrial sabotage. We also examined incidents involving political extremists, such as terrorist assaults and "symbolic" bombings, where a political statement and not the destruction of the target was the primary aim. Military commando raids provided data on attacks against heavily defended targets. In addition, a number of actual attacks upon nuclear plants, both here and in other countries, were included.

B. Common Elements

While acknowledging important differences between crimes for personal gain and those directed against nuclear programs, the researchers nonetheless felt that there were enough common elements to make comparisons useful. Both criminals and nuclear adversaries must, for example, assemble assault teams, gather intelligence, and force entry. Thus a study of criminal analogs yields much information that is pertinent to the defense of nuclear programs (Table I).

Assaults against protected and highly valuable targets (such as bank vaults, arsenals, and museums) were examined because they provide examples of remarkable planning and execution. In the cases reviewed, criminals were able to assemble large teams, devote up to two years to planning a single operation, breach thick walls and vaults, and get around modern alarm systems.

TABLE I

ANALOGS BEING EXAMINED IN THE RAND STUDY

Nonnuclear Analogs	Potential "Nuclear Action"
Symbolic bombings and incidents of violence against symbolic targets.	Attempts by political or environmental extremists to carry out acts of symbolic violence against nuclear facilities.
Incidents of industrial sabotage and sabotage of vital systems (electric transformers, transmission lines, natural gas lines, etc.).	Sabotage of nuclear facilities.
Task force burglaries, robberies, and attempts to "spring" prisoners from the outside.	Well-planned penetrations of protected nuclear facilities for the purpose of theft or sabotage; hijacking of nuclear material in transit.
Paramilitary commando raids.	Well-planned, heavily armed assaults against defended nuclear targets (unlikely in current political environment).
Terrorist assaults on embassies, government buildings, small settlements, etc.	Armed assaults on nuclear facilities for the purpose of theft, sabotage, or seizing control of nuclear facilities.

The thieves frequently displayed remarkable ingenuity. The reluctance of profit-minded criminals to take risks results in a reliance on deception (impersonation was frequently employed with high success), a method that might be used against nuclear facilities. Similarly, the criminals' ability to neutralize or bypass alarm systems has implications for the protection of nuclear programs.

C. The Terrorist

Terrorist assaults were reviewed because they involved highly dedicated individuals, who were willing to accept great personal hazard. Some--like those taking part in the attack on Lod airport--could almost be classed as suicidal. These two attributes--high motivation and the acceptance of extreme risk--the researchers regarded as particularly dangerous in a potential nuclear adversary. Unlike professional criminals, terrorists were quick to brandish weapons. Yet, they rarely attacked facilities when the probability that they might be defeated was great, and they chose conspicuous targets, like foreign embassies, that were certain to bring them maximum publicity.

A sample of small-scale military commando raids provided the researchers with the only incidents in which well-armed groups, specially trained and dedicated, attacked strongly defended targets. These cases proved the importance of accurate intelligence and the element of surprise.

D. The Saboteur

Sabotage directed against private industry, transportation networks and public utilities was particularly relevant to possible nuclear sabotage because both are likely to depend upon inside assistance.

The researchers included symbolic bombings in their survey because nuclear facilities may present tempting targets to extremists who view them as symbols of unwarranted and dangerous technology.

IV. PROFILE OF THE NUCLEAR ADVERSARY

A. The Typical and the High-Level Profile

After compiling their historical file, the researchers examined the analog incidents for common features. A range of key attributes emerged and from these, two composite adversaries were constructed: a "typical" and a "high-level" profile.

The typical profile represents a level of resources and skills that criminals have commonly been able to assemble, and, as such, might be able to bring to bear in the future on a nuclear facility (Table II). It consists of three to six people armed with automatic weapons, possessing high explosives and power tools, using a variety of ground transportation, enjoying access to some inside information, and displaying a moderate to high degree of technical skills, ingenuity, advanced planning, and risk acceptance.

The high-level composite represents the upper ranges of skills and resources thus far observed in real-life episodes (Table III). It consists of 12 to 20 adversaries well-versed in modern weaponry and military skills, highly dedicated and ingenious, having inside assistance, modern communications equipment, the ability to maintain secrecy and achieve tactical surprise, and a willingness to risk capture or death.

B. High-Level Composite Unlikely

It should be emphasized that the appearance of the high-level composite, with all the high-level attributes, is an unlikely event; the simultaneous appearance of all the characteristics has not appeared in any single adversary in the data base, with the possible exception of a few wartime commando raids. There are several reasons why this is so. First, it is difficult to assemble such a combination of skills and personnel. Second, such a combination might not have been perceived as necessary. Third, some of these high-level attributes are

TABLE II

HIGH-LEVEL COMPOSITE PROFILE OF ADVERSARY ATTRIBUTES AND CHARACTERISTICS

Adversary	Number of Perpetrators	Weapons Used	Tools Used	Mode of Transportation	Technical Skills	Dedication (willingness to risk death or capture)	Inside Assistance	Planning	Ingenuity and Imagination
High-level composite	12-20	Anything up to and including light, crew-served weapons	High explosives, power tools	Foot, commercial vehicles, air, sea	High[a]	High[a]	Information and help	High	High

[a]High dedication *and* high skill are not generally seen in a single "typical" group, with the notable exception of many commando raids.

TABLE III

TYPICAL COMPOSITE PROFILE OF ADVERSARY ATTRIBUTES AND CHARACTERISTICS

Adversary	Number of Perpetrators	Weapons Used	Tools Used	Mode of Transportation	Technical Skills	Dedication (willingness to risk death or capture)	Inside Assistance	Planning	Ingenuity and Imagination
"Typical" composite	3-6	Automatic weapons, grenades, shotguns, explosives	High explosives, hand and power tools	Foot, commercial vehicles, limited use of aircraft	Medium to high	Medium to high	Information or other assistance from one insider	High	Medium to high

mutually contradictory. For instance, the technical sophistication required to neutralize an electronic alarm system would be less important if the adversary planned to storm a facility with a large number of heavily armed men; similarly, the willingness to risk capture or death stands in partial contradiction to technical expertise, at least as seen in the present data base. This is equally true of the typical composite profile. The fact that such an assemblage has not been observed in any single adversarial group in the past does not imply that such a group could not be assembled in the future, especially given the large payoffs that nuclear facilities or programs might appear to offer to terrorist or criminal elements in terms of personal gain, political statements, or other possible incentives; but it should be re-emphasized that nothing approaching the high-level composite has been observed in the peacetime data base.

C. Implications of Composites

The composites held a number of implications for the design of security systems for nuclear plants. Notably, the attackers appear to have little difficulty obtaining the physical resources needed to assault an installation (Table IV). Nor do they seem to encounter serious obstacles in recruiting gang members, or procuring weapons, explosives, or special equipment. Moreover, the evidence suggests that large numbers may be no more effective than a small group of skilled people.

Instead, the critical constraints upon the adversaries seem to lie in the less tangible realm of imagination and ingenuity, criminal skills, technical knowledge, the willingness to risk capture or death, accurate intelligence, privileged access, the ability to achieve tactical surprise and the necessary combination of several of these factors.

The researchers reason, therefore, that a security system designed to compel a potential adversary to possess all of these critical human capabilities to a high degree might thwart most of the actions that could be directed against it and the programs it protects.

TABLE IV

COMPOSITE SUMMARIES OF ADVERSARY ATTRIBUTES AND CHARACTERISTICS DISPLAYED IN SIX "TYPICAL" ACTIONS

"Typical" Action	Number of Perpetrators	Weapons	Tools	Transport	Technical Skills	Dedication (willingness to risk death or capture)	Inside Assistance	Planning	Ingenuity and Imagination
Terrorist assault	3-6	Handguns, automatic weapons	High explo-sives	Foot, commercial vehicles, air	Medium	High	No	Medium to high	Medium to high
Robbery	3-6	Handguns, shotguns	None	Foot, commercial vehicles	Medium	Medium	Information	Medium	Medium to high
Burglary	2-4	Weapons usually not displayed	Hand and power tools, high explo-sives	Foot, commercial vehicles	High	Low to medium	Information	High	Medium to high
Bombing	1-2	None	Hand tools, explo-sives	Foot, commercial vehicles	Low to medium	Low	No	Medium	Low to medium
Sabotage	2-5	Usually none	Hand and power tools, explo-sives	Foot, motor vehicles	Low to medium	Low	Information and access	Medium	Medium to high
Commando raid	20-30	Automatic and light crew-served weapons, explosives	Hand tools, explo-sives	Foot, air, ship, and motor vehicles	High	High	Information	Medium to high	Medium to high

V. SECURITY SYSTEM DESIGNED TO THWART THE NUCLEAR ADVERSARY

How might such a system work? First, physical barriers, although necessary to delay or hinder attacks are not in themselves sufficient to prevent a determined enemy from gaining entry. Frequent monitoring of the defenses both electrically and by specially equipped guards is also required. Second, the prospect of physical danger seems to have some value in deterring attack, so it must be clear to potential terrorists that they are risking their lives. The third and perhaps greatest obstacle to a potential attacker is the deliberate creation of uncertainty by the security system. An armed guard force whose immediate strength and routines can never be confidently predicted makes it extremely difficult for an adversary to be confident his own resources are adequate.

The researchers also found that terrorists rarely assaulted facilities where there was a good chance of being defeated before they gained entry, but they were willing to assume high risks once inside. This implies that defense strategies should be geared to defeat the initial attack rather than to cope with the invaders once inside.

VI. ANALYSIS OF THE MOTIVATIONS AND INTENTIONS OF THE NUCLEAR ADVERSARY

This first phase of our study, reported to Sandia in 1977, told us only what kinds of resources and capabilities criminal adversaries might be able to assemble. It did not tell us why anyone would want to carry out an action against nuclear programs. Classic threat analysis consists of an assessment of capabilities <u>and</u> intentions. In the second phase of our research, we turned to an analysis of the motivations and intentions of potential criminal adversaries, a topic occasionally touched upon but not dealt with systematically in the first phase of research. We believe that understanding <u>why</u> certain adversaries might want to attack nuclear targets may help us anticipate what they might attempt to do and how. This, in turn, can be used to design more effective ways to protect nuclear programs and facilities.

Dealing with the question of why someone might commit a crime in the nuclear domain is necessarily more speculative. Our conclusions reflect a synthesis of findings from four separate lines of inquiry; a structural approach, a psychological approach, an analog approach, and an examination of past nuclear incidents.

A. The Structural Approach

In the structural approach, we posit the most likely combinations of perpetrators, motivations, and intentions, and then identify actions that would be congruous to them. For example, a disgruntled employee (whose motivation we would label "personal") might want to inflict economic damage upon his employer, perhaps by temporarily disrupting plant operation, or damaging equipment through such actions as vandalism, sabotage, and hoax bomb threats. Such actions would have less appeal to the group with economic motives, who would be more likely to turn to theft of material or to extortion schemes involving threats to personnel or facilities.

The structural approach does not attempt to penetrate deeply into the mind of the perpetrator and, in a sense, contains an element of tautology. Thieves steal. Terrorists terrorize. Nonetheless, it is useful as a means of identifying likely combinations of perpetrators and actions, and ultimately, of capabilities and targets.

B. The Psychological Approach

In the psychological approach, we attempt to penetrate the mindset of the adversary more deeply than we do in the structural approach, although we do not delve into unconscious motivations. By examining the communiques and manifestos of terrorist groups, the biographies and autobiographies of terrorists, and the various theories of terrorist behavior, we have gained some insights into the conscious motivations and intentions of terrorist groups as they pertain to the nuclear domain. Similarly, the literature on the criminal mind and criminal behavior yields some clues to the motivations of the potential nuclear adversary.

C. The Analog Approach

The third line of inquiry, the analog methodology used in our earlier study of adversary resources, capabilities and methods, is extended to examine the motivations and intentions of possible adversaries. We explore the motivations of various categories of criminals whose actions have been in some ways analogous to possible nuclear crimes. They include sophisticated burglars, arsonists, mass murderers, and psychotic bombers. The assumption is that those who might be prompted to undertake the analogous nuclear crime (e.g., theft of special nuclear material, or mass contamination by radioactivity) would reflect similar motivational patterns.

D. An Examination of Past Nuclear Incidents

Lastly, although serious criminal actions involving nuclear facilities or material have been few, there have been a large number of incidents of vandalism, minor sabotage, theft, and symbolic acts of violence at nuclear facilities. These incidents cover a spectrum of motivations including economic, political, anti-nuclear, environmental concerns, and psychosis. Such incidents free us from relying entirely on posited motives or analogs. Our fourth line of inquiry, then was to examine all such nuclear incidents for motivations, and compare our conclusions with those produced by the other lines of inquiry.

E. Motivations

The motivations that might prompt potential adversaries to undertake criminal actions against U.S. nuclear programs can be roughly divided into three categories: ideological, economic, and personal (Table V).

Ideological motivations are those linked to a political or philosophical system. They would include those of political terrorists, anti-nuclear extremists, and certain groups of philosophical/religious fanatics. These potential adversaries might target nuclear facilities hoping to influence government policy on nuclear energy or nuclear weapons; as a way of coercing changes in other (non-nuclear) areas of government policy; or perhaps as a way of undermining public confidence in the government and promoting political unrest.

Economic motivations involve a desire for financial gain. Both professional and amateur criminals might view nuclear material or weapons as potentially attractive targets for schemes of theft for ransom, sale, or extortion.

Personal motivations emerge from the special situations of specific individuals. Personal reasons for committing a nuclear-related crime would range from those of the hostile employee seeking to redress a grievance against his employer to those of the psychotic individual responding to an ideosyncratic perception of reality.

This three-way categorization of motivations is admittedly an oversimplification in that specific adversaries may not fit neatly into one of the three categories or may reflect more than one type of motivation at a given time. For example, a nuclear industry employee, anxious for revenge against his employer for a perceived injustice, might accept a bribe to furnish a criminal group with information about plant security procedures, thereby manifesting both personal and economic motivations.

TABLE V

POSSIBLE NUCLEAR-RELATED CRIMES

Adversary	Possible Crimes Involving the Security of U.S. Nuclear Facilities or Programs: Destroy or Disable Nuclear Facilities	Possible Crimes Involving the Security of U.S. Nuclear Facilities or Programs: Acquire Nuclear Material or Information	Possible Crimes Involving the Security of U.S. Nuclear Facilities or Programs: Disrupt Nuclear Programs	Crimes Not Involving the Security of U.S. Nuclear Facilities or Programs
Economic Motivation				
Professional criminals	Threaten or engage in sabotage in connection with extortion	● Theft (all categories) by stealth or force	Threaten or engage in kidnapping or violence against persons in connection with extortion or coercion	Nuclear threats in connection with extortion or coercion Sale or attempted sale of nuclear material
Occasional or novice criminals or opportunists	Threaten or engage in sabotage in connection with extortion	● Theft (all categories) not by force Diversion Theft of information Misuse of facility	Threaten or engage in kidnapping or violence against persons in connection with extortion or coercion Fake a diversion for the purpose of extortion Disclose classified information	● Nuclear threats in connection with extortion or coercion ● Sale or attempted sale of nuclear material
Ideological Motivation				
Political terrorists	High-level standoff attack ● Sabotage (all levels)	Theft (all categories)	● Threaten or engage in kidnapping or violence against persons ● Seize and hold a facility with (or without) hostages	Nuclear threats in connection with extortion or coercion Detonation of nuclear device or dispersal of nuclear material Fabrication of nuclear device
Antinuclear extremists	Low-level standoff attack ● Low-level sabotage High-level sabotage (?)	Theft (all categories) Theft or purchase of information	● Trespass ● Incite to illegal actions Seize and hold a facility (with hostages (?)) Disclose classified information	Nuclear threats
Philosophical or religious extremists	High-level sabotage Sabotage with radioactive release	Theft of SNM or nuclear weapons	Incite to illegal actions Threaten or engage in kidnapping or violence against persons Disclose classified information	Nuclear threats in connection with extortion or coercion Detonation of nuclear device or dispersal of nuclear material Fabrication of nuclear device
Personal Motivation				
Psychotics	(No action can be eliminated from the range of psychotic behavior)			
Individuals acting for idiosyncratic reasons	● Low-level standoff ● Low-level sabotage	Theft (all categories) not by force Diversion Theft or purchase of information	● Pranks, hoaxes, bomb threats Fake a diversion Disclose classified information	● Nuclear threats in connection with extortion or coercion Fabrication of nuclear device

Hostile employees	Low-level standoff ● Low-level sabotage High-level sabotage (?)	● Theft of non-SNM or small quantities of SNM Diversion Theft of information	Incite to illegal actions Trespass Seize and hold a facility (with hostages (?)) ● Hoaxes Threaten or engage in violence against persons Disclose classified information	● Nuclear threats in connection with extortion or coercion
In Service of Foreign Government				
Mercenaries, foreign agents, or foreign commandos	High-level standoff ○ High-level sabotage Sabotage with radio-active release	○ Theft (all categories) Diversion ● Theft or purchase of information ○ Misuse of facility	Engage in kidnapping or violence against persons ● Disclose classified information	Sale or attempted sale of nuclear material Detonation of nuclear device or dispersal of nuclear material Fabrication of nuclear device

NOTE: ● = occurred
○ = may have occurred

TYPES OF ADVERSARIES

Professional criminal: crime is main source of livelihood.

Occasional or novice criminal: may have criminal record but not a habitual offender.

Opportunist: takes advantage of opportunity for illegal gain; no prior criminal record.

Political terrorist: member of group aiming for political change through violent attacks.

Antinuclear extremist: commits illegal acts out of opposition to nuclear programs (for ecological, safety, political, or economic reasons).

Philosophical or religious extremist: beliefs would condone or encourage acts of mass destruction.

Psychotic: impaired personality or brain function; distorted view of reality.

Individual acting for idiosyncratic reasons: not psychotic, but driven to take illegal actions to satisfy egocentric motivations (e.g., exhibitionism, megalomania).

Hostile employee: nuclear industry employee motivated by specifically job-related grievances or labor-related conflict.

Mercenaries, foreign agents, and foreign commandos: knowingly and willingly serve foreign government. Mercenaries may include professional criminals or terrorists; "foreign agents" implies insiders acting covertly; "foreign commandos" implies paramilitary operation mounted by foreign power, not necessarily using nationals of that power.

TYPES OF ACTIONS

Theft (by stealth or force): matrix distinguishes three categories:

Theft of non-SNM: e.g., equipment, conventional explosives, unenriched uranium.

Theft of SNM: special nuclear material in quantity too small to fabricate nuclear weapon.

Theft of SNM in strategic quantities: e.g., a nuclear weapon, a nuclear weapon component, or enriched nuclear material sufficient to fabricate weapon.

Diversion: theft by insiders (or with insider assistance) designed to conceal loss by altering records.

Sabotage: matrix distinguishes three levels:

Low-level: vandalism or action intended to temporarily disrupt operations or disable facility.

High-level: destruction of a facility involving danger to human lives.

Sabotage with radioactive release: destruction of a facility intended to create radioactive release, endangering public safety.

Kidnapping or violence against persons: directed against nuclear industry officials or employees (or families) for coercion or intimidation.

Misuse of facility: unauthorized use of nuclear facility (e.g., to process stolen material).

Standoff attack: matrix distinguishes two levels:

Low-level: e.g., pistol or rifle fire directed against nuclear facilities or transport vehicles.

High-level: e.g., use of crew-served weapons (mortars or rocket-propelled grenade launchers), aerial bombing, or use of remotely piloted aircraft or vehicles carrying explosives.

Disclose classified information: unauthorized disclosure of classified information by those with legal access, for financial gain, to aid adversaries, or to influence or incite public.

Fake a diversion: create the appearance that nuclear material is missing by manipulating records, altering identity of containers, or concealing material within facility (for extortion, coercion, or disruption).

VII. FOREIGN AGENTS

We did not examine in detail the potential for crimes against U.S. nuclear programs or facilities by agents of foreign governemtns. This does not reflect a judgment that such crimes are less likely or important than those that might potentially be committed by the classes of domestic adversaries on whom we have concentrated. Rather, given our primary concern with motivations of domestic adversaries, we decided for the moment to defer research on the foreign agent.

The personal motivations of the agent himself seem less relevant to predicting potential actions than is the case with other types of adversaries, because he takes orders from his employer--the foreign government which he serves. Yet an analysis of the motivations of foreign governments for sponsoring criminal nuclear-related actions in the United States would take use into realms of international strategy that go beyond our immediate research agenda.

VIII. ACTION CATEGORIES

From defining the broad categories of adversaries, we then moved to identifying major categories of action. We identified actions aimed at destroying or disabling nuclear facilities, actions aimed at acquiring nuclear material or information, and actions aimed at disrupting nuclear programs. The researchers also recognized certain crimes that do not directly involve the security of U.S. nuclear facilities or programs but are nonetheless of concern because the response to such threats or actions could involve U.S. nuclear security officials and make special demands on security and safeguards systems. An example would be a nuclear extortion threat in which it becomes crucial to know whether any nuclear material has been taken.

The categories of potential adversaries are linked with the nuclear-related crimes that appear congruous with their motivations in a matrix (Table V). For example, political terrorists might launch high-level standoff attacks or attempt to penetrate nuclear facilities for the purpose of sabotage. They could threaten officials in nuclear programs or attempt to seize a facility as part of a campaign to disrupt nuclear programs. They could also make nuclear threats, and, if they acquired SNM, actually attempt to fabricate and detonate a nuclear device of some type.

In fact, they have done several of these things. In Spain and in France, terrorist groups have sabotaged nuclear facilities. In Spain, they have also kidnapped and threatened to kill officials connected with nuclear programs.

In this manner, we believe we are able to represent the full range of possible motivations and criminal actions that may be directed against nuclear programs. The matrix reflects our judgments that certain motivations are likely to generate certain actions. It does not reflect any assessment of probability of any of these actions occurring. And it does not reflect any assessment of capabilities. Certain actions may be attractive to certain kinds of adversaries; others may not. We make no statement here about the ability of any adversary to actually carry out his preferred action.

IX. MATCHING CAPABILITIES AND MOTIVATIONS

Of course, some adversaries are more likely to possess certain resources and capabilities than others. Matching capabilities--the subject of our earlier report--with motivations will be the next step in our research. After assembling the clusters of motivations, capabilities, and actions which will give us a more complex portrait of the spectrum of adversaries, we will assess the comparative likelihood of certain actions and relative target attractiveness.

X. CONCLUSIONS

Our study to date has led to a number of general conclusions. Nuclear defenders must anticipate a surprisingly wide range of threats from an equally wide array of potential adversaries, who may be animated by ideological, economic, or personal motivations, or some combination of the three. The spectrum of possible actions by these adversaries varies greatly in intensity from the adolescent prank to schemes of mass destruction.

Nuclear programs seem to have all of the adversaries faced by any large industry (e.g., disgruntled employees, environmentalists) as well as those faced by any industry that deals in a highly valuable commodity. Nuclear programs also attract some particular adversaries: opponents of nuclear energy and weapons development; political terrorists who view such programs as symbols of the political and economic system they wish to destroy; and emotionally unstable people obsessed by the almost mystical qualities of nuclear power. The fear invoked by the word "nuclear" in the minds of many people may provide a special attraction to certain categories of adversaries.

The presumed range of potential dangers to nuclear programs is not entirely hypothetical. There have already been many low-level actions--bomb threats against nuclear facilities, low-level sabotage, nuclear hoaxes--that provide examples of most of the categories of perpetrators and motives discussed in this report. Such low-level actions appear to have satisfied the aims of their perpetrators and therefore seem likely to occur again. There is little basis for extrapolating from them to higher-level incidents, however.

Only those adversaries driven by blind fanaticism or psychological abnormalities appear likely to attempt nuclear crimes aimed at producing widespread casualties.

The last several years have witnessed an increase in the number and seriousness of nuclear-related incidents. Although we have not seen acts of sabotage aimed at causing radioactive release, a number of incidents have occurred since 1977 in which adversaries demonstrated greater sophistication or willingness to cause casualties.

Owing to popular conceptions and misconceptions of nuclear energy, an incident of relatively harmless actual consequence conceivably could produce large-scale effects. A well-formulated hoax threat, for example, might conceivably cause panic.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #6: DOMESTIC ACCOUNTABILITY AND CONTROL FEATURES

SPEAKER: Dr. Ralph Lumb

President, NUSAC, Inc.
McLean, Virginia USA

Wednesday, May 28, 1980
8:30 a.m.

BIOGRAPHY

Education: Clark University, Worcester, Massachusetts, A.B. in Chemistry and Ph.D in Physical Chemistry

Present Position: Dr. Lumb is President of NUSAC, Incorporated. He develops management audit and review programs concerned with nuclear fuels quality assurance, nuclear material safeguards, and plant and material protection, and participates in training programs for client personnel.

Past Positions: From 1956 through 1960, Dr. Lumb was Project Leader and Vice President of Quantum, Inc., a research and development consulting firm based in Wallingford, CT. During this period he was responsible for design of the Nuclear Research Center for the University of Buffalo.

From 1951 through 1956, Dr. Lumb worked with the US Atomic Energy Commission in the Division of Nuclear Materials Management.

From 1948 through 1951, Dr. Lumb was an Assistant Professor at Assumption College and Northeastern University teaching general and physical chemistry.

Other Information: Dr. Lumb participated in the organization of the Institute of Nuclear Materials Management in 1958, and became the first Chairman of the Institute. Dr. Lumb contributed to the organization of the Niagara-Finger Lakes Section - ANS, and became its first Chairman. He is a Fellow of the American Society for the Advancement of Science and of the American Institute of Chemists.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #6: DOMESTIC ACCOUNTABILITY AND CONTROL FEATURES

The objectives of a domestic safeguards system will be identified; the motivating influences for the objectives will be examined; and the mechanisms for reaching the objectives will be explored. The choices that are applicable for a domestic safeguards system installation will be discussed and the timing concerns will be reviewed.

After the session, participants will be able to

1. Identify desired safeguards system objectives in the case of their own nation.

2. Understand the factors governing their selection of a domestic safeguards system.

3. Recognize the implementing problems associated with their choice of objectives.

SESSION 6: DOMESTIC ACCOUNTING AND CONTROL FEATURES

Ralph F. Lumb
NUSAC

I. INTRODUCTION

In considering a State system, I am going to discuss three major topics: (1) the objectives of a State system; (2) factors to consider in selecting a State system; and (3) mechanisms for achieving a satisfactory system. While these appear to be separate topics, in reality there is considerable overlap among them and none of them is capable of standing alone without the supportive features of the others.

For all of the discussions on the topic and the interest attached to it, it is relatively difficult to find a single statement of safeguards objectives that is completely satisfactory. However, I am going to give you one which I feel is meaningful and which may be a basis for your developing the safeguards objectives for your State:

"Safeguards measures are designed to deter, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion; and (2) sabotage of nuclear facilities. The safeguards program has as its objective achieving a level of protection against such acts to insure against significant increase in the overall risk of death, injury, or property damage to the public from other causes beyond the control of the individual."*

II. OBJECTIVES OF A STATE SYSTEM

In planning a state system that will be responsive to the needs of the government, one must consider a number of factors.

A. Administrative Control

The government should clearly identify the organization responsible for administering its program of nuclear activities. In the area of material accountability, there should be a single group that is responsible for the administrative functions.

B. Logistical Control

There is an essential need for both logistical and financial control of the nuclear materials within a State. It is important that a single group be able to identify the locations and the movements as well as the uses to which nuclear material are being put within the State's borders. In some instances there may be both publicly owned nuclear material and privately owned nuclear material within a State's borders, just as we have within the United States. But regardless of that consideration, the responsiveness of the State system cannot be avoided. All other arms of the government and of the public sector as well, have a

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*Chilk, Samuel J., Secretary of the Commission, "Safeguards Objectives," memorandum for Lee V. Gossick, Executive Director for Operations, SECY-75-729A, May 21, 1976.

right to expect a single source within the government to be aware of the activities associated with all nuclear material within the State's borders.

Finally, responsiveness to the government must encompass operational control requirements. In many instances, the government will not only oversee nuclear activities, but will enter into the activities as an operating entity. In such instances, it is essential that the government entity maintain excellent operational control if it is to serve as an example to the privately owned and operated facilities within its borders.

C. Timeliness

As you develop your State's domestic accountability system, the matter of timeliness will arise in many ways. Initially, there is the consideration of data collection. How will that be accomplished in a timely manner commensurate with the importance of the data? Once the data are collected, consideration must be given to the communication method that will facilitate data flow from the collection source to the accountability organization within the State. Finally, the time it will take to process the data through your system and put it in a form which can be used by your government as a source of information must be addressed.

Many times people give the answer "real time" when questions arise as to how quickly a state system should be able to function. Upon examination, you may find that the data are only collected twice a year or once a month, and then are put in the mail system to be delivered to the State. At that point someone

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apparent. Chemists, nuclear engineers, statisticians, and accountants must work together to achieve a reporting system with the maximum level of material accountability.

E. Accountability

The last consideration in identifying the objectives of a State system that I wish to address is accountability.

1. Centralized Control. The cornerstone of a strong accountability system lies in the development of centralized control within the system. If this concept can be established in the formative stages of your State's system development, it will greatly improve the development of the remaining portions of the system. Internal control relies on an ability to reproduce information whenever it is needed and upon an ability to know the sources of the information, to understand how these sources obtain their information, and the influence those sources can have on information. Strong internal control procedures in place at all levels of your nuclear program will greatly simplify your task of providing responsive and accurate information to your government.

2. Uniform Reporting. Uniform reporting requirements are essential to assure good accounting information. The decisions regarding what data are necesary should be made at the State level. The choice of documents that will accumulate the data and will transmit the data up to the State level represent decisions that you should make in developing your State system. However, the operational needs of your facilities should not be ignored or

overlooked in developing your reporting requirements. The State and operational requirements should go hand-in-hand, and whenever possible the State system should utilize operational data needed by the facilities.

3. Data Base. As your accounting system evolves, there will be clearly identifiable points where a comparison of data for different facilities is possible. These points should be developed to the maximum. In this manner, you will rapidly accumulate a data base which will allow you, from the State level, to compare the operations and the efficiency of operations of various facilities in your State. I might add that the IAEA, working throughout the world, is in a position to develop this type of comparative data more rapidly than anyone else. As a result, they will be able to identify differences in operating efficiencies from one State to another, and from one facility to another within a State. The advantages of this should be recognized, and if possible, the State should take advantage of any information the IAEA can provide to improve the State's operating effectiveness.

4. Definition of Responsibilities. In the development of the State's system, it is essential that responsibilities for material accounting, control, and custody be defined at all levels as clearly as possible.

A facility manager must accept responsibility for whatever is done with the nuclear materials in his facility's possession. His responsibility is supported by the accounting system, a service familiar to most of us. In this regard, if we can demonstrate that our system has maintained a documented record of everything regarding the material, then we do indeed have good material accounting. Of course, we may have documented the fact that the material was lost and then we have a problem, but the accounting would be considered excellent. Closely associated with material accounting is material control. If the control of its use and movement is tied in with the accounting system, and movement cannot occur without documentation in the accounting system, then you have responsibility that can be exercised properly.

The last level of responsibility is that of material custody. This normally involves recognition of a physical fact: a worker has material in his possession, or an operator has material in his machine, or an individual has material in a storage area for which he is the custodian. While in each instance the individual has certain responsibilities, the accountability for the material is rarely vested in that individual, nor is responsibility for where it will go next or how it will be used. An ability to establish these three levels of responsibility for nuclear materials (accounting, control and custody) will enhance the success of any State's internal control program.

III. FACTORS IN SELECTING A STATE SYSTEM

Having considered the primary objectives that must be dealt with in establishing a State system, let us consider some other factors in selecting a system. The recognition of these factors must not preclude achieving any of the objectives previously identified as essential to your system.

A. _rategic Importance

If the nuclear materials within your State are not readily useable in the construction of nuclear explosive devices, then strategic importance is not a major concern. If this is not the case, then it is imperative that consideration be given to this factor in the design of the State system. Many combinations of quantities and forms and types of nuclear material can contribute to a situation in which there is a stragically important holding of nuclear material within the State. Such a situation will have an important impact on the State system, but one should not allow this factor to completely dominate the selection of a system. The important thing to remember is that you must be able to respond in a positive and satisfactory manner to questions posed by either your government or the IAEA.

The number and complexity of nuclear facilities operating within your borders will obviously influence the type of system you develop. One or two research reactors, or even power reactors, do not equate to one reprocessing facility or fuel fabrication facility in terms of the considerations that will have to be brought to bear in the development of the State system.

One must consider the types of nuclear material to be dealt with in the system. Are they normal uranium, or plutonium and highly enriched uranium, or some mixture of all these? Are the materials in the form of fabricated fuel components, or metal bars and buttons? And finally, are you concerned with a thousand kilograms of normal uranium, or ten kilograms of plutonium, or is it a matter of a thousand kilograms of plutonium and ten kilograms of normal uranium? The decisions which must be made based on these questions will have a substantial impact on the system's design. Parallel with these decisions that you will be making primarily from the nuclear material safeguards viewpoint, consideration must be given to health and safety. It is important to consider all of these matters in the development of your accounting and control system to avoid duplication of effort, and to provide additional information and assurances that the system operates as intended.

B. Value of the Materials

At some point, consideration must be given to the value of the nuclear materials to be covered by the State system. Given that 3% uranium dioxide has a monetary value of approximately 700 US dollars per kilogram, it can readily be seen that the inventories held within a State's borders can be extremely valuable. It follows that the value of the nuclear materials must be recognized in the development of the system to be employed by the State in safeguarding its holdings.

Another consideration involves the economic impact on a State as a result of its nuclear material holdings. Is a loss of material going to shut down a power reactor? If so, are there alternative power sources upon which the area can rely? Unless realistic options exist, the economic importance to an area may dictate that the system used to safeguard the nuclear materials recognize the importance of the nuclear material - beyond just its monetary value.

The third value that must be given weight in developing the system is the so-called political value. This is probably the most difficult factor to come to terms with. The political impact attached to any mishap or mishandling of even the smallest quantity of nuclear material is totally out of proportion to any other values that can be identified for the material. If there are factions within a State opposed to the use of nuclear materials or to the possession of nuclear materials within the State, or factions that wish to embarrass the existing administration, any mishap, no matter how small, will be seized upon as a basis for embarrassing the government and interrupting the normal usage of nuclear materials. This must be recognized in developing your accountability system.

C. Geographic Distribution

Another factor which must be considered in developing the system involves the probable geographic distribution of nuclear materials within a State. The more movement of material that may occur within a State, the more consideration must be given to a system that will allow such logistics to be accommodated with appropriate accounting and physical protection. Also, geographic distribution of material will have an influence on data transmission methods. Recognition of these two activities, material movement and communication, will allow you to develop a system that will be responsive without overreacting and overburdening the accountability systems.

IV. MECHANISMS FOR ACHIEVING A SATISFACTORY STATE SYSTEM

In covering this topic, we will consider six activities that must be incorporated into any system developed for your State. They are: controls, reports, measurements, communications, physical security, and inspections.

In considering the type of a State system to be developed and implemented, one of the initial considerations should be a recognition of the types of facilities that the system will serve. Once the system is in place it should be flexible enough to accommodate materials at half a dozen facilities or many facilities. The first type of facility that many States encounter will be a research reactor. An outgrowth of research facilities may be the development of a waste storage facility. At some later date, power reactors may be established, and further down the road consideration may be given to the development of fuel fabrication facilities. Eventually, there may be chemical processing facilities for both hot and cold nuclear materials.

A. Controls

Let us again consider the question of controls. The choice is either centralized or decentralized control. If you are to be responsible for your system achieving its objectives, it is reasonable that you have some control over the manner in which they are met. Extreme geographic distances or vastly different types of facilities may suggest decentralization of control. However, it is rare when such circumstances override the advantages of centralization of the control function. The assurances that will come from having all data flow to a central point and all programmatic direction flow downward from a central point are most compatible with the responsibilities that are normally placed upon those in the centralized organization. Being able to go to one point, whether you are within the nuclear agency or in another branch of the government, is very helpful. Even if you may not have the answer readily given to you, you will know that you have reached the organization which will obtain the information you need as expeditiously as possible. This brings us to the question of timeliness. In the collection of data and the processing of it, if you know you have all the data to begin with, your task is made much simpler. Working through a centralized control system, one can measure the effectiveness of the system much more readily, and the system's accounting features can be more uniformly applied down through all levels of control.

If the number of nuclear facilities is small, then clearly a centralized control system will be the easiest to install and operate. However, if there are a large number of facilities within a State, and they are of different types, it may become difficult for any one group to maintain adequate control over all of them. At that time, it may be wise to consider decentralizing control. This may be accomplished by partitioning the control functions according to the type or the geographic location of the facilities or some other logical means which will allow the operating organizations to report to well-defined points. These "branch control points" in turn would report to a central government control agency. The government unit would then be responsible for assuring that all input is received prior to performing its functions. The system in the USA was developed in this fashion.

B. Reports and Automation

In the matter of data collection and reporting, we have basically two choices: either a manual system or an automated system. In practice, a mixture of both will probably arise and may be the best solution in most instances. Peer pressures may tend to lead you in the direction of automation of your accounting system. However, you may find that a manually-based system that can collect the data and prepare it for forwarding to a central location may be adequate. Even in those instances where computers exist within the facility, as in a power reactor, it may not be necessary or cost-effective to automate the nuclear materials accounting and control system. However, at the State level, it may be desirable to have a system which can be automated as it expands; initial design should not preclude this possibility.

The determination of whether a State system should be automated or should rely on manual records and reporting is an extremely important one. While there is no question that we live in an age of comput.rs (and in fact, some of your nuclear facilities may rely on computers to perform their functions), computers may not be the answer to every State's system of accounting and control. If many types of facilities possessing substantial inventories are to be established within your State, then I recommend that you automate as early and as completely as possible. Short of that, I urge extreme caution in the development of an automated system. Because of the structure of an automated system, objectives such as responsiveness, timeliness and accountability often will suffer in the initial stages of automation. It is only through very sophisticated software that these objectives can be met.

Few research facilities can justify the establishment of an automated system. Hardly any waste storage facilities can claim the need for one. Power reactors can function quite adequately without an automated system of accounting and control. It is not until you get into the area of fuel fabrication and chemical reprocessing that the complexities are such that automation is probably going to be of value. But even in these cases, the facilities' needs should be examined on their own merit.

Costs of automation are very high, running into the tens and hundreds of thousands of dollars for each facility, and that is only for the software and equipment. You will need to establish a relatively large professional staff to service an automated system. That is not to say that a State, now relying upon a manual accounting and control system for all of its facilities, should not consider the development of an automated system at the

State level. In the United States, the large majority of the nuclear facilities do not rely on automated system, yet the centralized nuclear materials accounting system employed by the government is automated, quite sophisticated, and extremely expensive.

C. Measurements

There are three times in the operational history of nuclear materials when measurements will be critical, (1) when material arrives in a State or at the facility, (2) when an inventory of materials is conducted, and (3) when the material is being removed from a facility or a State. In each instance, a decision must be made as to whether the measurements will be obtained independently, utilizing your own facilities, or whether the measurement values will be accepted as provided by the shipper or the receiver of the material. Further, a decision must be made as to whether the materials will be measured during inventory or reliance will be placed upon previously measured values obtained in the operational process.

Frequently the available instrumentation and other realities will determine whether you perform independent measurements. Consideration must also be given to the quantities of material involved and the importance of the measurement results. Even though you have a material which can be measured readily, if the amount is so small that its determination is not significant, it can hardly be justified that the State system establish its own independent measurement capabilities.

Since the majority of you are from technical backgrounds, I do not need to dwell on the cost of establishing analytical laboratories and staffing them with appropriately trained personnel. Both the staff and the equipment necessary for them to perform their functions are expensive and in short supply. Frequently, the decision to make an independent measurement can be contrary to many of the objectives of a system, since responsiveness, timeliness, effectiveness, and material accounting and control may suffer in the course of obtaining independent measurements.

Why then do we even consider establishing independent means of measurement? The factors that were initially identified in selecting your State system provide the answer. If strategic quantities of nuclear material are involved, the importance of independent measurements increases dramatically. If large numbers of nuclear facilities are built, the potential need for independent measurements will increase, and accordingly, the cost per measurement will decrease to an acceptable level.

The types, forms, and quantities of nuclear materials within a State will have a large bearing on the appropriateness of independent measurements. If the material is entirely in a form for which you justify the expense of a measurement, then there is no benefit to pursuing independent measurements in developing your accountability system. By the same token, if the value of the nuclear material in terms of monetary worth, economic importance, or political consideration is minimal, then it may be difficult to justify large expenditures to obtain independent measurements. All of these factors must be evaluated in arriving at the requirements for independent verification.

D. Communications

Along with the decision as to what data are to be collected, there is a follow up decision as to how these data are to be communicated to those who need them. One will seldom choose a single method, but rather, a combination of several methods. Such methods may involve electronic means, telephone, use of the National Postal System, or, in some instances, physical transport. In all probability the decisions will be in large measure dependent upon outside factors. The realities of the system of material accounting and control should guide you in selecting your communication needs. For example, it will be difficult to justify an electronic transmission system for data that are only required twice a year. That is not to say that valuable experience cannot be obtained through the utilization of electronic communications; rather, it will be hard to justify the extremely high costs of such a system.

Telephone communication links between facilities, and between facilities and the State level of control, are a more common mode. The telephone system will usually be in place and will not involve high expenditures to adapt it to the accounting system being considered. Use of a telephone input device that can be attached to a computerized data system is recommended to reduce transmission errors.

Initially the postal system will probably be the prefered mode of communication for a State's accounting and control system. Its simplicity, low cost, and the delivery of hard copies of data and reports give the postal system a strong advantage in most cases. It is only when data volume gets very large and timeliness of data processing becomes important that the more sophisticated means of communication should be considered.

E. Physical Security

The last operational mechanism having a bearing on the State system is that of physical security. In today's environment there will be very few truly open nuclear facilities. It then becomes a matter of degree as to how intensive the physical security needs to be at any given nuclear facility. It is sufficient to be aware of the physical security criteria and to be able to demonstrate that advantage has been taken of any assurances security can provide.

If research reactors located at an educational institution are involved, there is a strong need for a relatively open type of facility. Other types of facilities will involve more intensive levels of security. The objectives of a security system and the factors considered in selecting it may not be directly influenced by material control and accounting; however, there is a subtle interaction of the two systems. The clearance of personnel, control of personnel access to nuclear materials, and personnel monitoring all contribute to the material control system.

F. Inspections

On the assumption that the preceeding five activities have been implemented, it is important that a formal inspection program be developed to review actual practices at operating facilities and to verify the data in the State accounting system. No matter how carefully the procedures and instructions are developed for use by the facilities, you will find that there are differences in their interpretation and implementation. The adequate development of this inspection activity is extremely important to the credibility of a State system. It is only through inspection that assurance can be gained that the facilities are properly implementing the requirements of the State, and that the State records are valid.

To assure that the operational mechanisms are in place and functioning, it is necessary to develop an inspection capability at the State level. Depending on the number and complexity of the nuclear facilities within your State, this organization may be made up of the staff that performs the other functions of material accounting and control, or it may be necessary to establish a completely separate inspection group.

Whichever approach is taken, there are certain basic considerations which should be remembered and implemented in the performance of the inspection program itself. First, a considered and formalized inspection plan should be developed for each of the facilities to which an inspection is to apply. Since your basic purpose is to assure proper implementation of policies and instructions, it is necessary that you identify those points which you wish to review. Normally, an inspection program would encompass suitable examinations of all of the operational features that make up the first five mechanisms previously identified. The development of the inspection team and the necessity for it to travel to the facility takes time and is expensive in that it takes the staff away from its normal functions at the State level. Further, the presence of an inspection team at the facility tends to be disruptive to the normal operational procedures of the facility and that entails further expenses.

However, let us consider briefly the benefits of an inspection plan. First and foremost, there is the assurance that your guidlines are being properly implemented and that the State's records are correct. It is not uncommon to find that the State's guidance is being over implemented. Your evaluation of this situation may make it possibe to suggest modifications which can still accomplish the goals envisioned and also save time and money for the facility itself. Second, inspections give you an opportunity to see the facilities in their normal operating mode. It may then be possible to determine whether additional requirements should be established, or whether some of the existing requirements can be reduced or even eliminated. Finally, because of the ability of your inspection team to see the operation of several facilities, frequently of a similar nature, they can make suggestions to the individual facilities which may improve their operating efficiency without costing additional money or personnel. Most facilities are relatively isolated in terms of communications with other similar facilities, and your presence can be extremely helpful to them in discussing their problems and providing guidance in how they can cope with them.

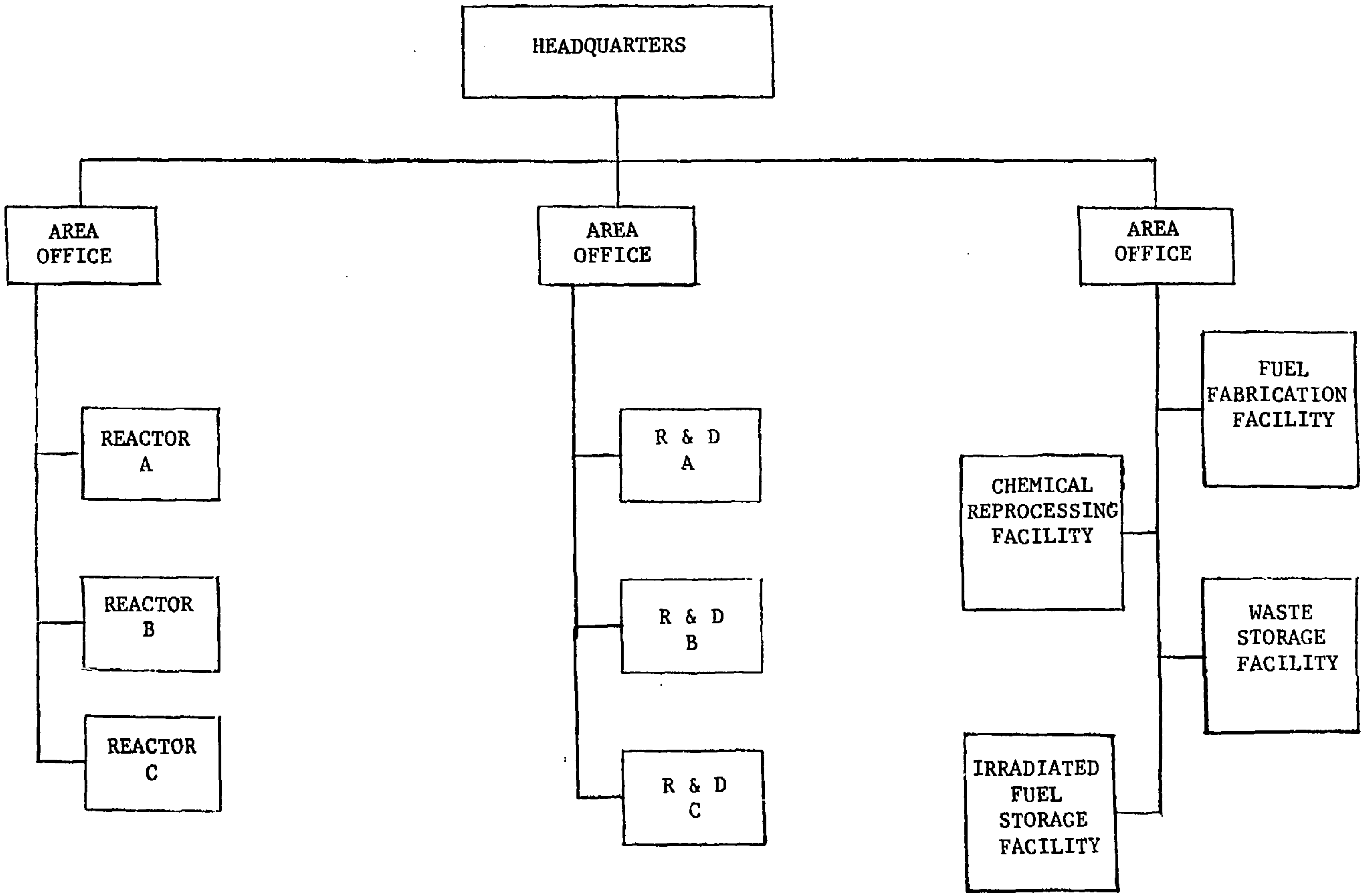
V. CONCLUSIONS

To summarize this discussion of the establishment of a domestic accounting and control system for nuclear materials, I would like to leave you with a few points. First, the selection of the system will be an individual choice of each State. Hopefully, the many considerations which I have discussed will be brought to bear in making that choice. In any event, I must stress the importance of simplicity. The simplicity of your selection must be matched by a realistic evaluation of the needs within your State, and an honest evaluation of the capabilities that will be made available to you to meet these needs. I hardly need remind you that you will be competing not only with other agencies of your government for funds, but also within your own agency you will be competing with other groups for the funds identified for nuclear programs.

At the earliest opportunity you must take steps to identify and establish the necessary professional cadre that you will need to bring the selected into being. That cadre must have professional competence in accounting and auditing, engineering, and statistics; as the complexity of activities grows, competence in chemistry, physics, non-destructive assay and electronic data processing must be added. You must try to obtain sufficient lead time in making this selection so that each individual can be trained and can contribute to the system effectively.

To the extent possible, I urge you to become familiar with the Institute of Nuclear Materials Management. This organization is made up of practicing professionals who are confronted with the same kinds of problems which you will face. Professional staff should be sent to topical meetings in the field of safeguards and materials management so they may keep abreast in their particular areas of expertise. And, of course, whenever possible, you should avail yourself of the opportunities offered by the IAEA to expand your understanding of nuclear material accounting and control.

A SUGGESTED SAFEGUARDS ORGANIZATION FOR STATE X



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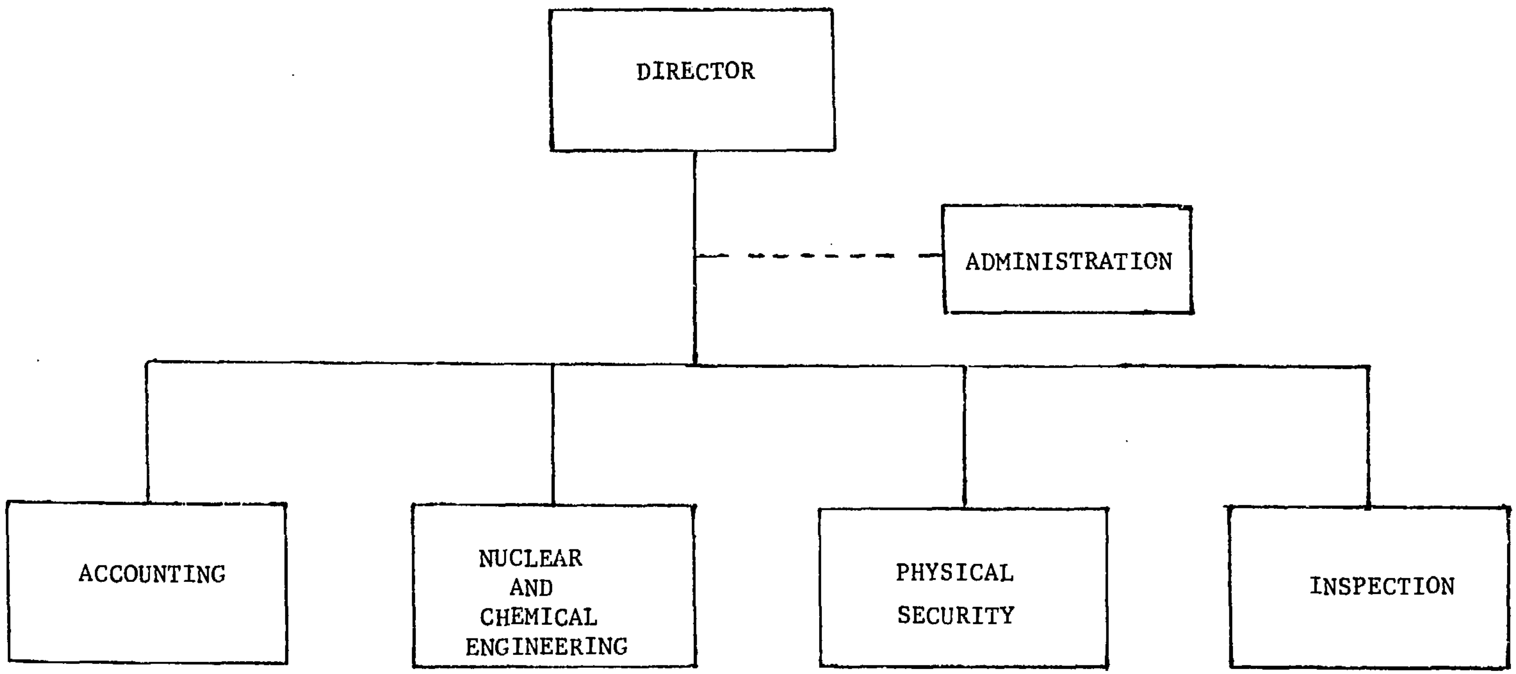

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #6: DOMESTIC ACCOUNTABILITY AND CONTROL FEATURES

SPEAKER: Dr. Ralph Lumb

President, NUSAC, Inc.
McLean, Virginia USA

Wednesday, May 28, 1980
8:30 a.m.

BIOGRAPHY

Education: Clark University, Worcester, Massachusetts, A.B. in Chemistry and Ph.D in Physical Chemistry

Present Position: Dr. Lumb is President of NUSAC, Incorporated. He develops management audit and review programs concerned with nuclear fuels quality assurance, nuclear material safeguards, and plant and material protection, and participates in training programs for client personnel.

Past Positions: From 1956 through 1960, Dr. Lumb was Project Leader and Vice President of Quantum, Inc., a research and development consulting firm based in Wallingford, CT. During this period he was responsible for design of the Nuclear Research Center for the University of Buffalo.

From 1951 through 1956, Dr. Lumb worked with the US Atomic Energy Commission in the Division of Nuclear Materials Management.

From 1948 through 1951, Dr. Lumb was an Assistant Professor at Assumption College and Northeastern University teaching general and physical chemistry.

Other Information: Dr. Lumb participated in the organization of the Institute of Nuclear Materials Management in 1958, and became the first Chairman of the Institute. Dr. Lumb contributed to the organization of the Niagara-Finger Lakes Section - ANS, and became its first Chairman. He is a Fellow of the American Society for the Advancement of Science and of the American Institute of Chemists.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #6: DOMESTIC ACCOUNTABILITY AND CONTROL FEATURES

The objectives of a domestic safeguards system will be identified; the motivating influences for the objectives will be examined; and the mechanisms for reaching the objectives will be explored. The choices that are applicable for a domestic safeguards system installation will be discussed and the timing concerns will be reviewed.

After the session, participants will be able to

1. Identify desired safeguards system objectives in the case of their own nation.

2. Understand the factors governing their selection of a domestic safeguards system.

3. Recognize the implementing problems associated with their choice of objectives.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 6: DOMESTIC ACCOUNTING AND CONTROL FEATURES

Ralph F. Lumb
NUSAC

I. INTRODUCTION

In considering a State system, I am going to discuss three major topics: (1) the objectives of a State system; (2) factors to consider in selecting a State system; and (3) mechanisms for achieving a satisfactory system. While these appear to be separate topics, in reality there is considerable overlap among them and none of them is capable of standing alone without the supportive features of the others.

For all of the discussions on the topic and the interest attached to it, it is relatively difficult to find a single statement of safeguards objectives that is completely satisfactory. However, I am going to give you one which I feel is meaningful and which may be a basis for your developing the safeguards objectives for your State:

> "Safeguards measures are designed to deter, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion; and (2) sabotage of nuclear facilities. The safeguards program has as its objective achieving a level of protection against such acts to insure against significant

increase in the overall risk of death, injury, or property damage to the public from other causes beyond the control of the individual."*

II. OBJECTIVES OF A STATE SYSTEM

In planning a state system that will be responsive to the needs of the government, one must consider a number of factors.

A. Administrative Control

The government should clearly identify the organization responsible for administering its program of nuclear activities. In the area of material accountability, there should be a single group that is responsible for the administrative functions.

B. Logistical Control

There is an essential need for both logistical and financial control of the nuclear materials within a State. It is important that a single group be able to identify the locations and the movements as well as the uses to which nuclear material are being put within the State's borders. In some instances there may be both publicly owned nuclear material and privately owned nuclear material within a State's borders, just as we have within the United States. But regardless of that consideration, the responsiveness of the State system cannot be avoided. All other arms of the government and of the public sector as well, have a

*Chilk, Samuel J., Secretary of the Commission, "Safeguards Objectives," memorandum for Lee V. Gossick, Executive Director for Operations, SECY-75-729A, May 21, 1976.

right to expect a single source within the government to be aware of the activities associated with all nuclear material within the State's borders.

Finally, responsiveness to the government must encompass operational control requirements. In many instances, the government will not only oversee nuclear activities, but will enter into the activities as an operating entity. In such instances, it is essential that the government entity maintain excellent operational control if it is to serve as an example to the privately owned and operated facilities within its borders.

C. Timeliness

As you develop your State's domestic accountability system, the matter of timeliness will arise in many ways. Initially, there is the consideration of data collection. How will that be accomplished in a timely manner commensurate with the importance of the data? Once the data are collected, consideration must be given to the communication method that will facilitate data flow from the collection source to the accountability organization within the State. Finally, the time it will take to process the data through your system and put it in a form which can be used by your government as a source of information must be addressed.

Many times people give the answer "real time" when questions arise as to how quickly a state system should be able to function. Upon examination, you may find that the data are only collected twice a year or once a month, and then are put in the mail system to be delivered to the State. At that point someone either in the government or in the public sector will expect the State system to be on a real time basis! Please do not build a system capable of real time information services and then stock the system with data collected only twice a year!

D. Effectiveness

Possibly the most difficult and controversial aspect of a State system is its effectiveness: how this effectiveness is measured, and how it is achieved. The functions contributing to your safeguards system effectiveness will be physical security, material control, and material accounting. Our discussion will focus upon the material control and accounting aspects.

The significance that you attach to the development of well-considered material balance areas, the establishment of storage facilities to hold your materials not in process, and the clear establishment of responsibility for the materials within a facility will all contribute to the effectiveness of your system. The effectiveness of your State's system will also depend to a large degree upon the material accountability requirements that you identify as necessary within your facilities and within your system. The means for achieving adequate and effective material accountability are quite well known and often extremely refined and sophisticated. A good reporting system based on carefully determined nuclear materials inventories will contribute significantly toward the establishment of an effective State system. It is in this area of materials accountability that the need for professional competence in several disciplines is most apparent. Chemists, nuclear engineers, statisticians, and accountants must work together to achieve a reporting system with the maximum level of material accountability.

E. Accountability

The last consideration in identifying the objectives of a State system that I wish to address is accountability.

1. Centralized Control. The cornerstone of a strong accountability system lies in the development of centralized control within the system. If this concept can be established in the formative stages of your State's system development, it will greatly improve the development of the remaining portions of the system. Internal control relies on an ability to reproduce information whenever it is needed and upon an ability to know the sources of the information, to understand how these sources obtain their information, and the influence those sources can have on information. Strong internal control procedures in place at all levels of your nuclear program will greatly simplify your task of providing responsive and accurate information to your government.

2. Uniform Reporting. Uniform reporting requirements are essential to assure good accounting information. The decisions regarding what data are necesary should be made at the State level. The choice of documents that will accumulate the data and will transmit the data up to the State level represent decisions that you should make in developing your State system. However, the operational needs of your facilities should not be ignored or

overlooked in developing your reporting requirements. The State and operational requirements should go hand-in-hand, and whenever possible the State system should utilize operational data needed by the facilities.

3. Data Base. As your accounting system evolves, there will be clearly identifiable points where a comparison of data for different facilities is possible. These points should be developed to the maximum. In this manner, you will rapidly accumulate a data base which will allow you, from the State level, to compare the operations and the efficiency of operations of various facilities in your State. I might add that the IAEA, working throughout the world, is in a position to develop this type of comparative data more rapidly than anyone else. As a result, they will be able to identify differences in operating efficiencies from one State to another, and from one facility to another within a State. The advantages of this should be recognized, and if possible, the State should take advantage of any information the IAEA can provide to improve the State's operating effectiveness.

4. Definition of Responsibilities. In the development of the State's system, it is essential that responsibilities for material accounting, control, and custody be defined at all levels as clearly as possible.

A facility manager must accept responsibility for whatever is done with the nuclear materials in his facility's possession. His responsibility is supported by the accounting system, a service familiar to most of us. In this regard, if we can demonstrate that our system has maintained a documented record of everything regarding the material, then we do indeed have good material accounting. Of course, we may have documented the fact that the material was lost and then we have a problem, but the accounting would be considered excellent. Closely associated with material accounting is material control. If the control of its use and movement is tied in with the accounting system, and movement cannot occur without documentation in the accounting system, then you have responsibility that can be exercised properly.

The last level of responsibility is that of material custody. This normally involves recognition of a physical fact: a worker has material in his possession, or an operator has material in his machine, or an individual has material in a storage area for which he is the custodian. While in each instance the individual has certain responsibilities, the accountability for the material is rarely vested in that individual, nor is responsibility for where it will go next or how it will be used. An ability to establish these three levels of responsibility for nuclear materials (accounting, control and custody) will enhance the success of any State's internal control program.

III. FACTORS IN SELECTING A STATE SYSTEM

Having considered the primary objectives that must be dealt with in establishing a State system, let us consider some other factors in selecting a system. The recognition of these factors must not preclude achieving any of the objectives previously identified as essential to your system.

A. Strategic Importance

If the nuclear materials within your State are not readily useable in the construction of nuclear explosive devices, then strategic importance is not a major concern. If this is not the case, then it is imperative that consideration be given to this factor in the design of the State system. Many combinations of quantities and forms and types of nuclear material can contribute to a situation in which there is a stragically important holding of nuclear material within the State. Such a situation will have an important impact on the State system, but one should not allow this factor to completely dominate the selection of a system. The important thing to remember is that you must be able to respond in a positive and satisfactory manner to questions posed by either your government or the IAEA.

The number and complexity of nuclear facilities operating within your borders will obviously influence the type of system you develop. One or two research reactors, or even power reactors, do not equate to one reprocessing facility or fuel fabrication facility in terms of the considerations that will have to be brought to bear in the development of the State system.

One must consider the types of nuclear material to be dealt with in the system. Are they normal uranium, or plutonium and highly enriched uranium, or some mixture of all these? Are the materials in the form of fabricated fuel components, or metal bars and buttons? And finally, are you concerned with a thousand kilograms of normal uranium, or ten kilograms of plutonium, or is it a matter of a thousand kilograms of plutonium and ten kilograms of normal uranium? The decisions which must be made based on these questions will have a substantial impact on the system's design. Parallel with these decisions that you will be making primarily from the nuclear material safeguards viewpoint, consideration must be given to health and safety. It is important to consider all of these matters in the development of your accounting and control system to avoid duplication of effort, and to provide additional information and assurances that the system operates as intended.

B. Value of the Materials

At some point, consideration must be given to the value of the nuclear materials to be covered by the State system. Given that 3% uranium dioxide has a monetary value of approximately 700 US dollars per kilogram, it can readily be seen that the inventories held within a State's borders can be extremely valuable. It follows that the value of the nuclear materials must be recognized in the development of the system to be employed by the State in safeguarding its holdings.

Another consideration involves the economic impact on a State as a result of its nuclear material holdings. Is a loss of material going to shut down a power reactor? If so, are there alternative power sources upon which the area can rely? Unless realistic options exist, the economic importance to an area may dictate that the system used to safeguard the nuclear materials recognize the importance of the nuclear material - beyond just its monetary value.

The third value that must be given weight in developing the system is the so-called political value. This is probably the most difficult factor to come to terms with. The political impact attached to any mishap or mishandling of even the smallest quantity of nuclear material is totally out of proportion to any other values that can be identified for the material. If there are factions within a State opposed to the use of nuclear materials or to the possession of nuclear materials within the State, or factions that wish to embarrass the existing administration, any mishap, no matter how small, will be seized upon as a basis for embarrassing the government and interrupting the normal usage of nuclear materials. This must be recognized in developing your accountability system.

C. Geographic Distribution

Another factor which must be considered in developing the system involves the probable geographic distribution of nuclear materials within a State. The more movement of material that may occur within a State, the more consideration must be given to a system that will allow such logistics to be accommodated with appropriate accounting and physical protection. Also, geographic distribution of material will have an influence on data transmission methods. Recognition of these two activities, material movement and communication, will allow you to develop a system that will be responsive without overreacting and overburdening the accountability systems.

IV. MECHANISMS FOR ACHIEVING A SATISFACTORY STATE SYSTEM

In covering this topic, we will consider six activities that must be incorporated into any system developed for your State. They are: controls, reports, measurements, communications, physical security, and inspections.

In considering the type of a State system to be developed and implemented, one of the initial considerations should be a recognition of the types of facilities that the system will serve. Once the system is in place it should be flexible enough to accommodate materials at half a dozen facilities or many facilities. The first type of facility that many States encounter will be a research reactor. An outgrowth of research facilities may be the development of a waste storage facility. At some later date, power reactors may be established, and further down the road consideration may be given to the development of fuel fabrication facilities. Eventually, there may be chemical processing facilities for both hot and cold nuclear materials.

A. Controls

Let us again consider the question of controls. The choice is either centralized or decentralized control. If you are to be responsible for your system achieving its objectives, it is reasonable that you have some control over the manner in which they are met. Extreme geographic distances or vastly different types of facilities may suggest decentralization of control. However, it is rare when such circumstances override the advantages of centralization of the control function. The assurances that will come from having all data flow to a central point and all programmatic direction flow downward from a central point are most compatible with the responsibilities that are normally placed upon those in the centralized organization. Being able to go to one point, whether you are within the nuclear agency or in another branch of the government, is very helpful. Even if you may not have the answer readily given to you, you will know that you have reached the organization which will obtain the information you need as expeditiously as possible. This brings us to the question of timeliness. In the collection of data and the processing of it, if you know you have all the data to begin with, your task is made much simpler. Working through a centralized control system, one can measure the effectiveness of the system much more readily, and the system's accounting features can be more uniformly applied down through all levels of control.

If the number of nuclear facilities is small, then clearly a centralized control system will be the easiest to install and operate. However, if there are a large number of facilities within a State, and they are of different types, it may become difficult for any one group to maintain adequate control over all of them. At that time, it may be wise to consider decentralizing control. This may be accomplished by partitioning the control functions according to the type or the geographic location of the facilities or some other logical means which will allow the operating organizations to report to well-defined points. These "branch control points" in turn would report to a central government control agency. The government unit would then be responsible for assuring that all input is received prior to performing its functions. The system in the USA was developed in this fashion.

B. Reports and Automation

In the matter of data collection and reporting, we have basically two choices: either a manual system or an automated system. In practice, a mixture of both will probably arise and may be the best solution in most instances. Peer pressures may tend to lead you in the direction of automation of your accounting system. However, you may find that a manually-based system that can collect the data and prepare it for forwarding to a central location may be adequate. Even in those instances where computers exist within the facility, as in a power reactor, it may not be necessary or cost-effective to automate the nuclear materials accounting and control system. However, at the State level, it may be desirable to have a system which can be automated as it expands; initial design should not preclude this possibility.

The determination of whether a State system should be automated or should rely on manual records and reporting is an extremely important one. While there is no question that we live in an age of computers (and in fact, some of your nuclear facilities may rely on computers to perform their functions), computers may not be the answer to every State's system of accounting and control. If many types of facilities possessing substantial inventories are to be established within your State, then I recommend that you automate as early and as completely as possible. Short of that, I urge extreme caution in the development of an automated system. Because of the structure of an automated system, objectives such as responsiveness, timeliness and accountability often will suffer in the initial stages of automation. It is only through very sophisticated software that these objectives can be met.

Few research facilities can justify the establishment of an automated system. Hardly any waste storage facilities can claim he need for one. Power reactors can function quite adequately without an automated system of accounting and control. It is not until you get into the area of fuel fabrication and chemical reprocessing that the complexities are such that automation is probably going to be of value. But even in these cases, the facilities' needs should be examined on their own merit.

Costs of automation are very high, running into the tens and hundreds of thousands of dollars for each facility, and that is only for the software and equipment. You will need to establish a relatively large professional staff to service an automated system. That is not to say that a State, now relying upon a manual accounting and control system for all of its facilities, should not consider the development of an automated system at the

State level. In the United States, the large majority of the nuclear facilities do not rely on automated system, yet the centralized nuclear materials accounting system employed by the government is automated, quite sophisticated, and extremely expensive.

C. Measurements

There are three times in the operational history of nuclear materials when measurements will be critical, (1) when material arrives in a State or at the facility, (2) when an inventory of materials is conducted, and (3) when the material is being removed from a facility or a State. In each instance, a decision must be made as to whether the measurements will be obtained independently, utilizing your own facilities, or whether the measurement values will be accepted as provided by the shipper or the receiver of the material. Further, a decision must be made as to whether the materials will be measured during inventory or reliance will be placed upon previously measured values obtained in the operational process.

Frequently the available instrumentation and other realities will determine whether you perform independent measurements. Consideration must also be given to the quantities of material involved and the importance of the measurement results. Even though you have a material which can be measured readily, if the amount is so small that its determination is not significant, it can hardly be justified that the State system establish its own independent measurement capabilities.

Since the majority of you are from technical backgrounds, I do not need to dwell on the cost of establishing analytical laboratories and staffing them with appropriately trained personnel. Both the staff and the equipment necessary for them to perform their functions are expensive and in short supply. Frequently, the decision to make an independent measurement can be contrary to many of the objectives of a system, since responsiveness, timeliness, effectiveness, and material accounting and control may suffer in the course of obtaining independent measurements.

Why then do we even consider establishing independent means of measurement? The factors that were initially identified in selecting your State system provide the answer. If strategic quantities of nuclear material are involved, the importance of independent measurements increases dramatically. If large numbers of nuclear facilities are built, the potential need for independent measurements will increase, and accordingly, the cost per measurement will decrease to an acceptable level.

The types, forms, and quantities of nuclear materials within a State will have a large bearing on the appropriateness of independent measurements. If the material is entirely in a form for which you justify the expense of a measurement, then there is no benefit to pursuing independent measurements in developing your accountability system. By the same token, if the value of the nuclear material in terms of monetary worth, economic importance, or political consideration is minimal, then it may be difficult to justify large expenditures to obtain independent measurements. All of these factors must be evaluated in arriving at the requirements for independent verification.

D. Communications

Along with the decision as to what data are to be collected, there is a follow up decision as to how these data are to be communicated to those who need them. One will seldom choose a single method, but rather, a combination of several methods. Such methods may involve electronic means, telephone, use of the National Postal System, or, in some instances, physical transport. In all probability the decisions will be in large measure dependent upon outside factors. The realities of the system of material accounting and control should guide you in selecting your communication needs. For example, it will be difficult to justify an electronic transmission system for data that are only required twice a year. That is not to say that valuable experience cannot be obtained through the utilization of electronic communications; rather, it will be hard to justify the extremely high costs of such a system.

Telephone communication links between facilities, and between facilities and the State level of control, are a more common mode. The telephone system will usually be in place and will not involve high expenditures to adapt it to the accounting system being considered. Use of a telephone input device that can be attached to a computerized data system is recommended to reduce transmission errors.

Initially the postal system will probably be the prefered mode of communication for a State's accounting and control system. Its simplicity, low cost, and the delivery of hard copies of data and reports give the postal system a strong advantage in most cases. It is only when data volume gets very large and timeliness of data processing becomes important that the more sophisticated means of communication should be considered.

E. Physical Security

The last operational mechanism having a bearing on the State system is that of physical security. In today's environment there will be very few truly open nuclear facilities. It then becomes a matter of degree as to how intensive the physical security needs to be at any given nuclear facility. It is sufficient to be aware of the physical security criteria and to be able to demonstrate that advantage has been taken of any assurances security can provide.

If research reactors located at an educational institution are involved, there is a strong need for a relatively open type of facility. Other types of facilities will involve more intensive levels of security. The objectives of a security system and the factors considered in selecting it may not be directly influenced by material control and accounting; however, there is a subtle interaction of the two systems. The clearance of personnel, control of personnel access to nuclear materials, and personnel monitoring all contribute to the material control system.

F. Inspections

On the assumption that the preceeding five activities have been implemented, it is important that a formal inspection program be developed to review actual practices at operating facilities and to verify the data in the State accounting system. No matter how carefully the procedures and instructions are developed for use by the facilities, you will find that there are differences in their interpretation and implementation. The adequate development of this inspection activity is extremely important to the credibility of a State system. It is only through inspection that assurance can be gained that the facilities are properly implementing the requirements of the State, and that the State records are valid.

To assure that the operational mechanisms are in place and functioning, it is necessary to develop an inspection capability at the State level. Depending on the number and complexity of the nuclear facilities within your State, this organization may be made up of the staff that performs the other functions of material accounting and control, or it may be necessary to establish a completely separate inspection group.

Whichever approach is taken, there are certain basic considerations which should be remembered and implemented in the performance of the inspection program itself. First, a considered and formalized inspection plan should be developed for each of the facilities to which an inspection is to apply. Since your basic purpose is to assure proper implementation of policies and instructions, it is necessary that you identify those points which you wish to review. Normally, an inspection program would encompass suitable examinations of all of the operational features that make up the first five mechanisms previously identified. The development of the inspection team and the necessity for it to travel to the facility takes time and is expensive in that it takes the staff away from its normal functions at the State level. Further, the presence of an inspection team at the facility tends to be disruptive to the normal operational procedures of the facility and that entails further expenses.

However, let us consider briefly the benefits of an inspection plan. First and foremost, there is the assurance that your guidlines are being properly implemented and that the State's records are correct. It is not uncommon to find that the State's guidance is being over implemented. Your evaluation of this situation may make it possibe to suggest modifications which can still accomplish the goals envisioned and also save time and money for the facility itself. Second, inspections give you an opportunity to see the facilities in their normal operating mode. It may then be possible to determine whether additional requirements should be established, or whether some of the existing requirements can be reduced or even eliminated. Finally, because of the ability of your inspection team to see the operation of several facilities, frequently of a similar nature, they can make suggestions to the individual facilities which may improve their operating efficiency without costing additional money or personnel. Most facilities are relatively isolated in terms of communications with other similar facilities, and your presence can be extremely helpful to them in discussing their problems and providing guidance in how they can cope with them.

V. CONCLUSIONS

To summarize this discussion of the establishment of a domestic accounting and control system for nuclear materials, I would like to leave you with a few points. First, the selection of the system will be an individual choice of each State. Hopefully, the many considerations which I have discussed will be brought to bear in making that choice. In any event, I must stress the importance of simplicity. The simplicity of your selection must be matched by a realistic evaluation of the needs within your State, and an honest evaluation of the capabilities that will be made available to you to meet these needs. I hardly need remind you that you will be competing not only with other agencies of your government for funds, but also within your own agency you will be competing with other groups for the funds identified for nuclear programs.

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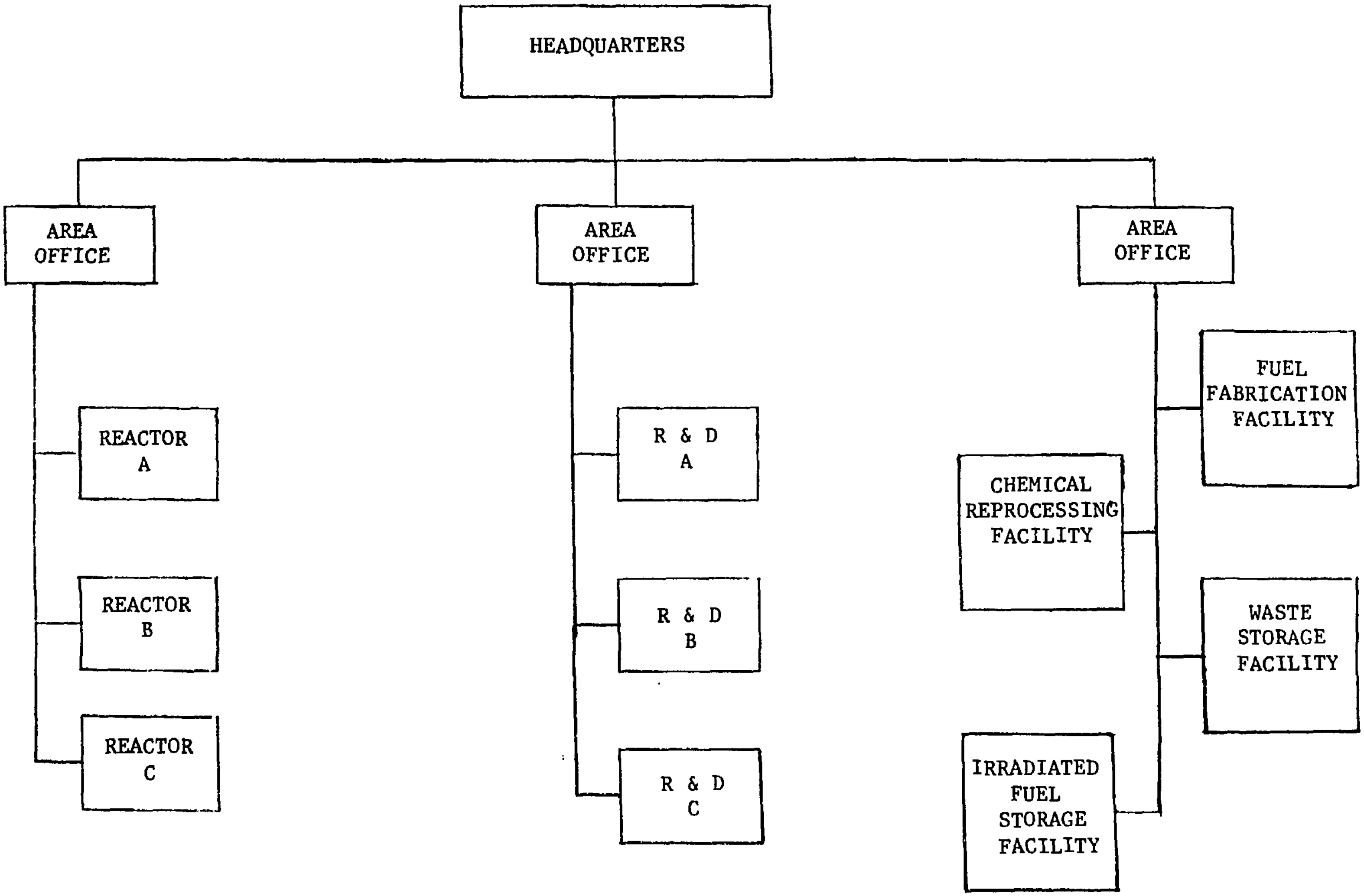
To the extent possible, I urge you to become familiar with the Institute of Nuclear Materials Management. This organization is made up of practicing professionals who are confronted with the same kinds of problems which you will face. Professional staff should be sent to topical meetings in the field of safeguards and materials management so they may keep abreast in their particular areas of expertise. And, of course, whenever possible, you should avail yourself of the opportunities offered by the IAEA to expand your understanding of nuclear material accounting and control.

A SUGGESTED SAFEGUARDS ORGANIZATION FOR STATE X



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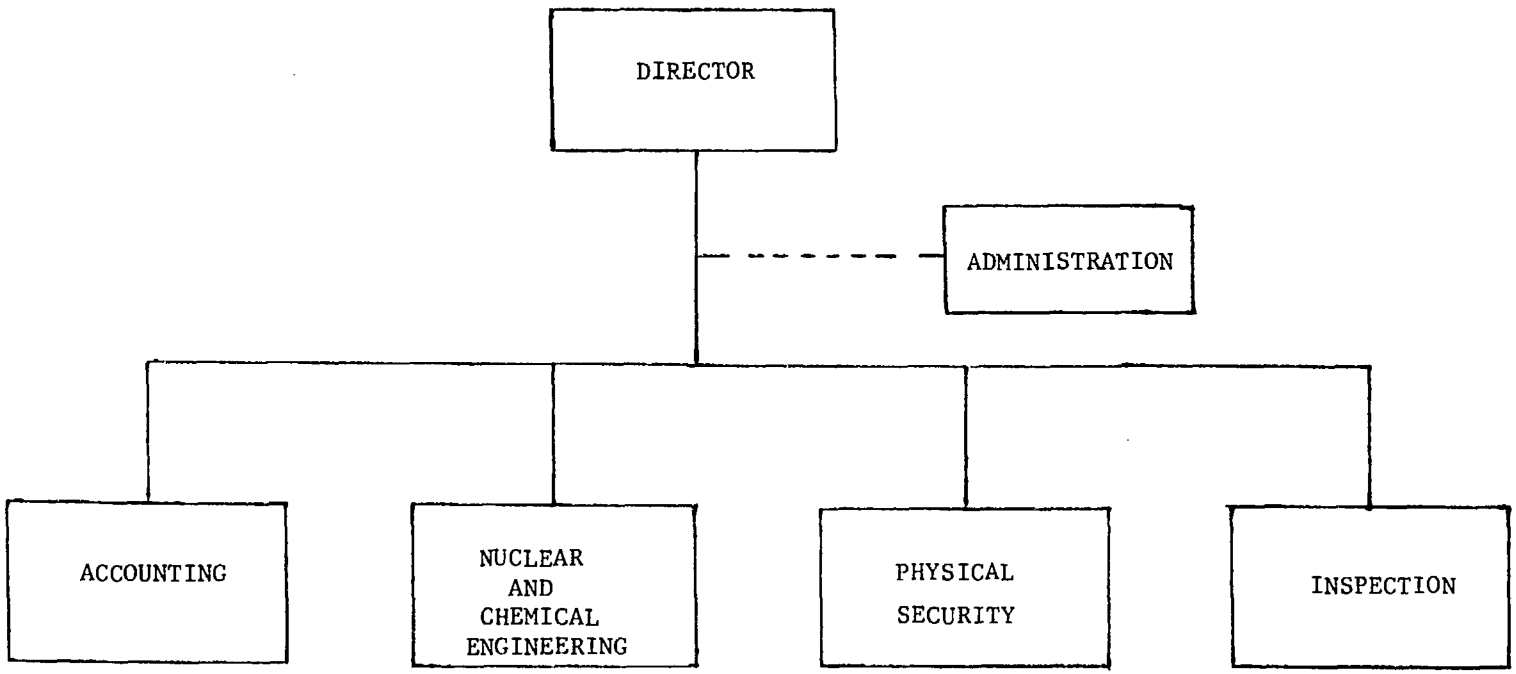

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #7: EURATOM SAFEGUARDS AS A MULTINATIONAL SYSTEM

SPEAKER: Ugo Miranda

EURATOM Safeguards Inspection
Kirchberg, Luxembourg

Wednesday, May 28, 1980
10:30 a.m.

BIOGRAPHY

Present Position: Head of Inspections and Control Techniques Section for Euratom Safeguards (Directorate E of General Directorate XVII (Energy) of the Commission of the European Communities)

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #7: EURATOM SAFEGUARDS AS A MULTINATIONAL SYSTEM

The political and legal framework of the the European Communities will be outlined to show the relationship between the European Coal and Steel Community, the European Economic Community (the "Common Market"), and the European Atomic Energy Community, Euratom. The Euratom Treaty will be examined in more detail as the basis for the multinational safeguards system applied since 1958. The Euratom safeguards system will be described with respect to records, reports, accounting and inspections.

The relationship between the Euratom safeguards system and the IAEA system will be described in some detail in view of the breadth and complexity of the fuel cycles that exist within the Community and in view of the three different Agreements with the IAEA relating to the seven Non-Nuclear Weapon State Members, to the UK (signatory to the NPT), and to France.

After the session, participants will be able to

1. Have an appreciation of the Euratom safeguards system;
2. Recognize how it differs from a single State system;
3. Recognize how it deals with a widely developed nuclear industry under a series of differing safeguards requirements.

Session 7: EURATOM SAFEGUARDS: AN EXAMPLE OF A MULTINATIONAL SYSTEM

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I. GENERAL INTRODUCTION

In establishing the European Coal and Steel Community (ECSC) and subsequently, in 1958, the European Economic Community (EEC) and the European Atomic Energy Community (Euratom), West Germany, France, Italy and the Benelux countries set up between them a new method of international cooperation designed to bring about a merging of their economies by progressive stages. In 1973 the United Kingdom, Denmark and Ireland joined the Community bringing the membership up to nine nations. Such economic integration involves not only the creation of a common market within which there can be freedom of movement for persons, services, goods and capital, but also the development of common policies in a growing number of economic sectors, and in particular agriculture, transport, business trends, energy and monetary organization.

All these integration measures go to form "the foundations of an ever closer union among the peoples of Europe" (Preamble to the EEC Treaty), which is the ultimate political aim. In the field of external relations, these measures are designed to enable the Communities to take their place in the world as a soundly organized unit, capable as such of exercising rights and fulfilling obligations.

It is from the standpoint of its institutional organization that the Community's pattern of cooperation differs most from the traditional inter-state forms. Its distinctive nature consists of the transfer to common organizations of powers hitherto the exclusive province of state sovereignty. Under the relevant provisions in the Treaties establishing them, the European Communities have prescriptive powers of their own and authority to enter into agreements with non-member states or international organizations.

Internally, the Communities have the power to make regulations and take decisions, the former of general application, the latter of specific scope: which are directly binding not only upon the Member States themselves but also upon natural or legal persons pursuing their activities in the territory of the Six. They may also, by means of directives, call upon Member States to take appropriate measures to achieve the objectives which they have set. Externally, the Communities are empowered to enter into commitments with other subjects of international law in matters which come within their competence on the internal plane.

This power to create rights and obligations is combined with supervisory and punative powers enabling the European Communities to ensure that the rules which they have laid down are duly complied with by the Member States and their nationals.

By the autonomous powers which have been conferred on them, the Communities set up organizations which, while allowing the Member States to retain all the powers which they have not surrendered to the Communities, act as a higher authority than these states in matters specified in the basic Treaties. The Communities are therefore legal persons distinct from the Member States, having an autonomous legal capacity that is quite different from that of most international organizations.

While they are certainly "multinational," since they have been set up by common accord between several states and these same states are members of them and are specifically represented in one of the four institutions, namely, the Council, the term "multinational" does not, in the case of the Communities, mean that all their acts are the result of a consensus among the Member States. It is sufficient to point out, as we do later on, that the Commission assumes its tasks without receiving instructions from the Member States; that it can commit the Member States; that it may institute proceedings against them before the Court of Justice; that the Court for its part may sanction infringements of the Treaty or of the acts for implementing it; and furthermore, that the Parliament exercises its powers without regard to its members' nationalities, to show that the Communities, far from being a mere conglomeration of states, are genuine entities of a new kind, with a will of their own.

By the Treaty (called the "Merger" Treaty) "establishing a Single Council and a Single Commission of the European Communities," which came into force in 1967, all the powers conferred upon the three Communities are exercised by the same institutions, namely, the Commission, the Council, the Parliament and the Court of Justice. This has been a major step along the road of unification. All matters which are the subject of economic policy in the broad sense, embracing not only agriculture, industry, social policy, transport policy but also the energy sector, and in particular nuclear energy in all its aspects, are now administered by the same bodies.

At the present stage, economic activity in the nine Member States is governed by a set of rules enacted, in the form of regulations, decisions or directives, on the sole responsibility of the Communities. In their external relationship, the Communities as such have concluded a large number of agreements for cooperation and association which are the most tangible expression of the unity they represent. In several fields, moreover, these powers are exclusive of those of the Member States.

Before defining the powers and instruments available to the European Atomic Energy Community and in particular those relevant to safeguards, it is as well to recapitulate briefly the dovetailing of the powers of the four Institutions which together constitute authority in the Community.

II. INSTITUTIONAL STRUCTURE OF THE EUROPEAN COMMUNITIES

A. The Commission

The Commission is the pivot of the Communities' institutional machinery. It is from the Commission that, as a general rule, the initiative in Community action comes; at the other extreme, it is the Commission which ensures that the rules are put into effect and which has powers to ensure that they are complied with. Its fundamental characteristic is its independence. Its members, who are of different nationalities, do not act as representatives of their country of origin. They are appointed on the grounds of their competence and, "in the general interest of the Communities, are completely independent in the performance of their tasks." Only the Court of Justice may compulsorily retire a member of the Commission if he is in breach of these obligations. In the cases provided for in the Treaties, the Commission has the power to adopt regulations and directives and to make decisions. Where such powers are reserved to the Council, it is the Commission which takes the initiative in the form of a proposal without which the Council cannot act. Being responsible for seeing that the Treaties are applied, the Commission may impose direct sanctions on persons or undertakings, e.g., in the field of safeguards, and may take proceedings against the Member States. It is responsible for negotiating international agreements.

B. The Council

The Council, which is composed of representatives of the governments of the Member States, is the institution which has, in addition to the powers conferred on it by the Treaty to make regulations, take decisions and issue directives, the task of coordinating the policies of the Member States and of the Community. It is in the Council, therefore, that in the normal course of events the interests of the individual Member States vis-a-vis those of the Community as a whole will find expression.

The powers of the Commission and those of the Council are very closely interlinked--so much so that, under the provisions of the Treaties, permanent cooperation is set up between these two institutions. As has just been said, the Council can exercise its powers as regards regulations, decisions and directives only on proposals from the Commission, which is a guarantee that the general interests of the Community will be taken into consideration. Moreover, the Council adopts the budgets on the basis of drafts submitted to it by the Commission after scrutiny by the Parliament.

C. European Parliament

The Commission is accountable to the European Parliament, whose members are elected directly by the European electors, mainly by proportional representation systems of voting for multi-member constituencies. Within the Parliament they have formed themselves into groups according to their political affinities, and not according to their nationality.

The Parliament takes part in the making of rules of law by means of the opinions which it is mandatory for them to deliver in cases specified in the Treaties. In matters concerning safeguards, for example, the Parliament has to be consulted if the procedures for applying such safeguards would have to be adjusted to new circumstances.

The Parliament's budgetary powers were strengthened about 10 years ago, at the same time as a system was adopted under which the Commission will have its own resources and thus enjoy increased financial autonomy.

The Parliament also has powers of political supervision. Each year it gives its verdict on the annual general report on the activities of the Communities which is submitted to it by the Commission. In addition, members of the Parliament have the right at any time to put oral or written questions to the Council and the Commission. Power of supervision may, in extreme cases, take the form of a motion of censure involving the resignation of the Commission as a body. Whereas the Court may compulsorily retire a member of the Commission from office on the basis of legal criteria, Parliament's appraisal in the exercise of its right of censure may be solely of a political nature.

D. The Court

The Court, whose complete independence is guaranteed by the Treaty (Judges may be relieved of office only on judgement passed unanimously by the other Judges), is the "guardian of the law" in the application and interpretation of the Treaties and the acts for implementing them.

It rules on the legality of the acts of the Commission and the Council. In certain matters it has unlimited jurisdiction, a case in point being when the Community's non-contractual liability is involved, or again, in actions brought against sanctions imposed by the Commission in connection with safeguards. The Commission, the Council and any Member State may contest the legality of regulations, directives and decisions issued by the Council or the Commission.

Persons and undertakings have the right to bring actions directly before the Court. They may contest any decisions which affect them, even if such decisions have been made in the form of a regulation. They may also, in proceedings in which a regulation is in issue, invoke the inapplicability of that regulation.

Thus any Member State and even, in the conditions described above, any person or undertaking may submit for censure by the Court any coercive acts by the Council and the Commission. This secures the legal systems set up by or in implementation of the Treaties against any illegal application or amendment.

The "direct relations," therefore, between the Commission and the Council on the one hand and persons and undertakings on the other also obtain where the Court is concerned. Not only do private persons and undertakings have the right of direct recourse to the Court, but also the latter's judgements are directly binding on such persons and undertakings without any action being required from the Member States. The Court's judgements are enforceable; they are enforced according to the rules of the national law, without any other formality than verification of the authenticity of the decision. This direct link between the judicial power and private persons and undertakings constitutes an unprecedented example of the application of a revolutionary principle to conventional international law.

It is important to emphasize not only that the Court Judges are independent of the national authorities but also that the law they apply takes precedence over national laws. In the event of a clash between a provision of national law, even if adopted subsequently, and a provision of Community law, the latter prevails and involves non-application of the former in the case in question. From this it follows that the Member States have neither the power nor the means to derogate from Community law unilaterally, or even concertedly, by enacting rules contrary to such law.

From the foregoing survey it is seen that each institution's activity is closely linked to that of the others. Each of them possesses, within the sphere of its competence and in the exercise of its own responsibility, effective ways of preventing and, if necessary, penalizing any action which conflicts with the Treaty aims or with the Community's international commitments.

When it is considered that the division of responsibilities and powers is rendered still more efficient by the operation of multinational factors, it will be quite clear that the institutional structure is in itself a guarantee that the Community legal systems function properly and that the obligations assumed by the Community, particularly in the field of nuclear material safeguards, are duly complied with.

III. AIMS AND POWERS OF EURATOM

The fundamental task of the European Atomic Energy Community is to create the conditions necessary for the development of a powerful nuclear industry. For this purpose, it has been invested with considerable powers to promote research and dissemination of information, health and safety, the development of industry, the organization of the nuclear material market and supervision over the use of such materials--to name only the most important of its fields of action. The Community has also been given powers to contribute to international cooperation by entering into external agreements.

A. Research and Dissemination of Information

The Commission's task is to coordinate research undertaken at the national level and complement it by carrying out a Community programme. This programme is adopted by the Council and implemented by or under the authority of the Commission, partly in the four establishments owned by the Community and together forming the Joint Research Centre (JRC) and partly under contract.

The Treaty not only secures the dissemination and use by the Member States, persons and undertakings of information derived from the Community research programme but also lays down a system for the communication of information and the granting of licenses under patents derived from non-Community research.

B. Health and Safety

In the field of health and safety, the Council has adopted directives establishing "basic standards," i.e., the maximum permissible doses and exposure and contamination levels, and the fundamental principles of medical surveillance. Furthermore, the Commission may make recommendations and issue directives to the Member States concerning harmonization of the applicable legal provisions, particularly dangerous experiments, radioactive waste disposal projects or, more generally, levels of radioactivity in the atmosphere, water and soil.

C. Development of Industries

By means of illustrative programmes, the Commission must attempt to guide and coordinate investments in the Community. To that end, it must be notified of all investment projects. It discusses with the persons and undertakings concerned all aspects of investment projects which relate to the objectives of the Treaty and finally makes known its views, which it communicates to the Member States under whose jurisdiction the undertaking comes. By this procedure the Commission obtains detailed advance information on all industrial and research installations to be set up in the Community, which is of considerable significance from the standpoint of the safeguards.

In order to add to the Community's industrial potential, undertakings which are of fundamental importance to the development of the nuclear industry may be established by the Council, on a proposal from the Commission, as "Joint Undertakings." These are corporate bodies which have legal personality in each of the Member States, are subject to whatever legal rules the Council may itself determine and may, depending on requirements, be exempt from ordinary company law. They may be financed by means of assets contributed by persons and undertakings of different Member States, the Community itself, non-member countries, international organizations or nationals of non-member countries.

D. Materials

Under Chapter IX of the Euratom Treaty, headed "The Nuclear Common Market," freedom of movement of materials, goods and products falling within the nuclear sector was adopted as early as 1959 and a common customs tariff was established. Chapter VI, "Supplies," goes much further in the integration of markets, for it introduces centralization at Community level of all transactions of which nuclear materials are the subject.

All producers are required to offer their production to the Supply Agency, an organ of the Community which has legal personality and financial autonomy. It has a right of option on all such materials. It centralizes application from users. The contracts resulting from examination of the supply-and-demand situation may only be concluded by the Agency. This exclusive right to enter into contracts also holds good for supplies of materials from outside the Community. Even though this system has been made more flexible and proposals have been made for securing still greater flexibility, the fact remains that the Agency has powers to ensure that all users have access, without discrimination, to all available resources. Furthermore, the system affords an accurate idea of movements of materials at any time, as well as of the use which market operators intend to make of them. In this regard, the Euratom supply system is one of the supports and at all events the starting-point, of the safeguards arrangements, which are precisely designed to check that there is no diversion from the intended use.

E. External Relations

The community has been invested with the power to enter into obligations by concluding agreements or contracts with a non-community state, an international organizational or a national of a non-Community state. This power is not exclusive, as the Member States have not been deprived of the power to enter into international agreements in the nuclear field, but the exercise of such power must be consistent with the commitments undertaken by the Member States when they established the Community.

IV. THE COMMUNITY'S POWERS AS REGARDS SAFEGUARDS, SUPPLY AND OWNERSHIP

Within the institutional structure set up by the Euratom Treaty, the responsibility for safeguards has been entrusted to the Commission. The extent of this responsibility and the scope and purpose of safeguards have been confirmed by a recent Ruling of the European Court of Justice, in which attention has been drawn to the complementarity of the provisions in the Treaty concerning safeguards measures (Chapter VII), supply arrangements (Chapter VI) and property ownership (Chapter VIII). The Parties to the Treaty have declared themselves as anxious to create the conditions of safety necessary to eliminate hazards to the life and health of the public; the expression "safeguards" in the Treaty, used to characterise the provisions of Chapter VII, has a wider scope than the mere substitution of a different destination for the one declared by a user of nuclear materials; the Treaty here envisages all diversions of nuclear materials entailing a security risk, that is to say the danger of interference with the vital interests of the public and the States.

A. Safeguards

Having responsibility for safeguards, the Commission has been invested with most of the powers provided for in Chapter VII of the Euratom Treaty.

1. Basic Requirements. Regulation n° 3227/76, which is directly applicable to every person or undertaking using or storing nuclear materials, establishes the obligations they have:

- o to communicate the technical characteristics of their installations to the Commission;
- o to carry out material accountancy and
- o to transmit appropriate advance notification and reports to the Commission.

2. Transmission of Required Reports. The Commission receives directly from those subject to such requirements, without intervention by the national authorities, the declarations and reports referred to in the regulation specified above.

3. Facility Access. Inspectors, who in the territory of the nine Member States have at all times access to all data in order to verify the truth of communications made by those subject to such requirements, come under the exclusive authority of the Commission (Art. 81).

4. Infringement Directives. Without prejudice to other measures available to it in respect of Member States, the Commission may issue directives calling upon the Member States to bring to an end an infringement that the Commission has detected (Art. 82).

5. Sanctions. The Commission may impose sanctions on persons and undertakings in cases of infringement of their obligations in this field. Such sanctions range from a mere warning to withdrawal of materials. In accordance with the general system under the Treaty, they are directly enforceable and for that purpose do not require any action by the national authorities, save the simple formality of verifying the authenticity of the document. Member States are required to lend assistance in remedying infringements discovered by the Commission.

From the foregoing it follows that the Treaty has created between the Commission and those subject to the safeguards system direct links which are set up without any action by the Member States under whose jurisdiction such persons come, and are set up at all stages--at the regulation stage, at the enforcement stage and at the sanctions stage. For their part, the persons and undertakings concerned have, as has been said above, the right to take proceedings before the Court of Justice against the Commission's decisions. They may also involve the Commission's responsiblity and demand that any damage caused them, whether by the Commission's decisions or by acts of its servants, be made good (Art. 188 of the Treaty).

To all these powers is added one which the Commission must employ when it considers that a Member State has failed to fulfill any of its obligations (Art. 141). Thus the Commission has a means of coercion which enables it to ensure that the Member States render it every assistance in applying safeguards and sanctions in their territories where the Commission's resources are not sufficient to deal with recalcitrants. By reason of the very broad terms in which Article 192 of the Treaty is couched, the scope of these powers is vast indeed.

B. Supply Arrangements

Article 52 of the Treaty provides that the supply of ores, source materials and special fissile materials shall be ensured "by means of a common supply policy." For this purpose an agency (The Euratom Supply Agency) is established possessing "a right of option on ores, source materials and special fissile materials produced in the territories of Member States and an exclusive right to conclude contracts relating to supply of ores, source materials and special fissile materials coming from inside the Community or from outside." As regards ores, source materials or special fissile materials coming from outside the Community the Supply Agency has an exclusive right, under Article 64, to enter into agreements or contracts relating to the supply of such products "acting where appropriate within the framework of agreements concluded between the Community and a third State or an international Organization." It follows from Article 60 in conjunction with Article 65 that the Supply Agency must be used as the intermediary between users of ores, source materials and special fissile materials and suppliers who are outside the Community. Even where the supply of products falling within the jurisdiction of the Supply Agency is provided "inter alia" by agreements or contracts between a Member State, an international organization or a national of a third State on the other, the prior consent of the Commission is necessary--in the terms of Article 73--for the conclusion or the renewal of the agreement or contract.

These provisions, amongst others, show the care taken in the Treaty to define in a precise and binding manner the exclusive right exercised by the Community in the field of nuclear supply in both internal and external relations.

C. Property Ownership

Article 86 says: "Special fissile materials shall be the property of the Community. The Community's right of ownership shall extend to all special fissile materials which are produced or imported by a Member State, a person or an undertaking and are subject to the Safeguards provided for in Chapter VII."

Article 87 says: "Member States, persons or undertakings shall have the unlimited right of use and consumption of special fissile materials which have properly come into their possession, subject to the obligations imposed on them by this Treaty, in particular those relating to safeguards, the right of option conferred on the Agency and health and safety."

The system of property ownership established by the Treaty means that, whatever the use to which nuclear materials are put, the Community remains the exclusive holder of those rights which form the essential content of the right of ownership. Thus, in the final analysis, the Community retains the right to dispose of special fissile materials; that concept is the basis of the supply arrangements. In contrast to the right of use and consumption which, for the purpose of economic exploitation, is divided between many different holders, the right of ownership of fissile material has been concentrated by the Treaty in the hands of a common public authority, namely the Community; therefore, it is the Community, and the Community alone, which is in a position to ensure that in the management of nuclear materials the general needs of the public are safeguarded.

D. Summary

To sum up we can say that the Community has general responsibility for the normal functioning of the nuclear common market. The safeguards provided for in Chapter VII of the EAEC Treaty relate to any diversion of nuclear materials entailing a security risk.

This chapter defines not only the objectives and purpose of nuclear material safeguards in the European Community, but provides also the legal basis for its practical application. In particular, it obliges operators to make declarations to the Commission on the basic technical characteristics of the facilities, and in the case of a chemical reprocessing plant, to ask for approval of the process used (Art. 78).

It requires the operators to maintain and produce operating records to permit accountability of the materials (Art. 79). It states that the Commission shall recruit inspectors who may be sent into the territories of the Member States, where they shall have at all times access to all places and data to the extent necessary to control the nuclear material (Art. 81 and 82). It defines, furthermore, actions to be taken in the case of non-compliance of a state or an installation, and states penalties

(Art. 82 and 83). Another input to the system comes from the Euratom Supply Agency, which enables the Safeguard directorate to verify arrivals and possible limitation of use.

Before describing (in a later section) the organizational structure of the Euratom safeguards system and its relationship to the IAEA Safeguards system it is necessary to summarize the main characteristics of this system.

It is a safeguards system, with supranational power on the Member States, which guarantees the safe use of nuclear materials. The Member states are amongst the most industrialized in the world; two of them are Nuclear weapon states (France and United Kingdom), all the others have adhered to the NPT. There exists a direct line of communication between the Commission of European Communities (primarily its Safeguards Directorate) and the plant operators; the users or holders of nuclear materials are responsible directly to the Commission for all the safeguards matters. The role of the member states is to assist the Commission in the exercise of its rights.

The Commission is, in the field of the safeguards, the unique correspondent on the European territories and applies the relevant prescriptions contained in Agreements with all other states, e.g. the USA, Canada (Australia is under negotiation), and in the "peaceful use" clauses in contracts with suppliers in other countries.

The right of inspection is unlimited, and the scope of inspection activities is restricted only by the wording of the Treaty, "... to the extent necessary to control ores, source materials and special fissile materials and to ensure compliance with the provisions of Article 77," and by no other regulation.

The Euratom inspectors are appointed "for life," as established, permanent, European civil servants.

The Commission applies the sanctions foreseen in the Euratom Treaty in case of transgression.

The application of Euratom safeguards is limited to the European Communities territory. The principle contained in the Treaties is of the non-discrimination between states: the safeguard measures have to be applied in the same way on all the materials independently of their location.

V. COMMISSION REGULATION 3227/76

The provisions of Commission Regulation 3227, adopted in 1976, replaced the previous Regulations 7 and 8 which had been issued in 1959. This regulation modified the safeguard procedures in the light of technical developments and takes into account the obligations arising from the Verification Agreement between the Community, the Non Weapon States and the IAEA.

A. Scope

Article 1 defines the most important category of person and undertakings subject to the Regulation: "any person or undertaking setting up or operating an installation..." and "any person or undertaking responsible for the storage...". Other less important categories are established in Articles 29 to 34, viz. ore procedures, ore exporters, nuclear material carriers and intermediaries of all sorts.

B. Basic Technical Characteristics

Article 1 also defines the obligation to declare to the Commission the "basic technical characteristics" of the relevant installations.

The title "basic technical characteristics" includes information, relevant to any specific installation, which helps the control authority to define the basic framework in which safeguards will be applied to the installation.

The basic technical characteristics are declared to the Commission on the basis of the relevant questionnaire given in annex 1. This annex consists of 7 questionnaires each of which refers to a type of plant or a group of specific plants and closely resembles the equivalent IAEA "Design Information Questionnaire."

In general, the answer to these questionnaires allow the Commission:

- to identify the installation, to know the location, owner, operator, general characteristics, etc.
- to qualify the nuclear materials used therein
- to define their use, and if relevant, the flow pattern
- to obtain a detailed description of the activities concerning the management, the handling, the measurements and the accountancy of the nuclear materials
- to have a knowledge of the internal rules which are necessary for the application of safeguards.

C. Basic Concepts of the Safeguards System

The Regulation implies a safeguards system which must be applied to the nuclear materials handled in the installation. The definition of nuclear material is given in Article 36, paragraphs i, e, f, g and h. Those materials used or simply stored in the installations are implicitly defined in Article 1. The operators are obliged to follow special rules for the accountancy of such material and to keep the Commission informed about this accountancy.

The general rules relevant to these topics are dealt with in paragraph 2 of the Regulation and in Annexes II to IV.

The implementation of the safeguards system requires that each installation be organized in one or more material balance areas (MBA). An MBA is an area, in most cases geographically defined or within pre-established boundaries, chosen in such a way that a material balance becomes possible and meaningful. It is not excluded that an MBA may be defined only in a functional way: in this sense the geographical overlapping of two or more MBA's is possible. The feasibility criterion for an MBA requires that at least the two following conditions are satisfied:

- every transfer into or out of the MBA must be determinable,
- it must be possible to determine the physical inventory of all the nuclear materials present in the area every time it is prescribed, and in accordance with specific procedures.

Criteria relevant to the definition of the MBA's are always indicated case by case and always discussed with the operators concerned.

It is important to note that different types of MBA exist which reflect different real situations relevant to the types of nuclear material, their use, the accountancy techniques adopted, and other objective characteristics which result in a different evaluation of the balances.

The verification of the information relevant to the entries to a material balance implies the knowledge of all the details of such entries. For this purpose a system has been designed which should allow an easy and clear transmission of information and the simultaneous indication of the sort of measurement system used to provide the accountancy data for a movement or an inventory taking.

In each MBA, key measurement points (KMP's) are suitably chosen. Their legal definition is found in Article 36 (q). They are locations where nuclear material appears in such a form that it may be measured to determine material flow or inventory.

It is clear that two KMP categories exist: one relevant to the determination of the material balance entries concerning the inventory changes and the other relevant to the inventory entries. These KMP's are defined as flow KMP's and inventory KMP's respectively. Sometimes these KMP's may be physically identical but their difference lies in their use. The KMP's are defined by the control authority after consultation with the operator concerned. The latter will indicate the methods he utilizes to derive the quantities of nuclear materials determined in each KMP. All the operations inherent in these determinations involve the preparation of accountancy and operational records as provided for in general terms in Articles 10 and 11.

D. Particular Safeguard Provisions (PSP)

In a regulation of general application it is possible to define the practical procedures for the implementation of the prescribed provisions only in quite general terms. The specific obligations imposed upon every single operator for the implementation of safeguards are included in another document called the Particular Safeguards Provisions (PSP), foreseen by the Regulation in Article 7. These provisions will be drawn up by means of an "individual decision" of the Commission. Both the operator and the Member State concerned are consulted on the content of the draft of the PSP, but they have no power of approval or veto.

The PSP is not a unified text detailing all obligations imposed on an operator but is a collection of particular provisions for the operator, the general provisions of the Regulation remaining fully applicable.

It is useful to recall that the facility attachments (established on the basis of the agreements with the IAEA) are arrangements agreed between the IAEA and the Community but do not in themselves impose obligations on the installations concerned. The Commission is, however, able to satisfy the commitments undertaken with the IAEA by means of the obligations imposed on the Community operators which are prescribed in general terms in the Regulation and for specific cases in the PSP.

The Regulation does not prescribe any direct connection between FA and PSP so that the adoption of the PSP is legally possible and may be necessary even in the absence of an agreement with the IAEA concerning the relevant FA.

1. PSP - MBA and KMP Definition. Article 7 gives the list of the main provisions which must be included in PSP. The first group of provisions are described in paragraph (a) which says that PSP will include "the designation of the material balance areas and the selection of those strategic points which are key measurement points for determining the flow and stocks of nuclear materials." The strategic points are defined in Article 36 (w).

The provisions concerning "strategic points" have been included in the Regulation to recall the limitation of access for IAEA inspectors during the execution of their duties. It is clear that this access limitation does not apply to the Commission inspectors who are covered by Article 81 of the Treaty of Rome.

2. PSP Records and Recording Procedures. The detailed requirements concerning the operating, accounting and reporting records, described in general terms in Articles 10 and 11, are included in the PSP.

Article 36 (k) defines the batch as "a portion of nuclear material handled as a unit for accounting purposes at a KMP...". The basic technical characteristics must indicate the measurement system used (if any) for the qualitative and quantitative determination of nuclear materials. On the basis of this information, occasionally supplemented by consultations with the plant operators, the Commission is able to do the following:

- judge the adequacy of the operator's measurement system (Article 9, paragraph 2),
- define the typical batches to be used in the accountancy,
- prescribe the source data which must be traceable in the records.

It is thus evident that an unbreakable link exists between the batch data, which are reported to the Commission, and the set of data or measurements used for their generation.

This chapter of the PSP gives particular prescriptions relevant to the following topics:

- records pertinent to the quality control carried out by the operators,
- standard procedures used by the accounting system for the generation of operational and accounting data,
- documentation of each event triggering the preparation of a special report,
- (for reactors) the procedures of recording and reporting nuclear transformations in agreement with Article 19, last sentence.

3. PSP - Physical Inventory. The obligation of the operators to periodically close the nuclear material balance by determining the physical inventory is one of the few basic technical innovations of Regulation 3227 in comparison with its predecessor. The physical inventory must cover all the nuclear

materials present at a specific moment in time within the MBA. The frequency of the physical inventory takings and the relevant procedures makes it possible to ensure that the inventory is correct and complete. The details of this important operation are also included in the PSP. All these rules are defined only after proper consultation with the plant operators who are subject to these prescriptions.

4. PSP - Advance Notifications to the Commission. In addition to the two sources of information which allow the Commission to prepare the PSPs:

- the answers to the questionnaires for the declaration of the basic technical characteristics (Article 1 and Annex I),
- the consultations foreseen in Article 8,

there is a third source of information which has been designed to receive advance notice of specific and foreseeable events relevant to safeguards activities. This matter is dealt with in Article 6 and Annex X, in general terms.

It is mainly on the basis of this quantified information that the Commission will decide on the frequency of the physical inventories necessary for the application of safeguards.

The other requirements mentioned in Annex X are easily understood by remembering the duties of the Community as control authority.

The verification of the material balance implies the physical verification of all or most of the quantities recorded in the accounts. In most cases this physical verification may take place only at specific intervals. The above-mentioned advance notifications are then necessary to plan this type of control.

The Regulation cannot foresee all the pieces of information necessary to the control authority in every case. It is for this reason that the penultimate paragraph of Article 7 indicates one of the chapters of the PSP's. The knowledge of the basic technical characteristics of each plant allows a clearer indication of the content of the communications required by Article 6. Another aspect of the advance notification is in relation to the basic technical characteristics. It is possible that the operators modify some of the characteristics originally declared. Some of these characteristics may be directly linked with the safeguards scheme defined by the Commission and may induce a change in such a scheme. If this is the case, the Commission will be notified in advance about the changes which the operator intends to make. The list of the possible variations for which an advance notification is mandatory is given in the PSP.

5. PSP - Containment and Surveillance. These techniques are used by the control authority when it is physically difficult, if not impossible, to verify by measurement batches of nuclear material already measured. Expressed in simpler terms, containment means the use of technique which allows the unique identification of a quantity of material (one or more batches or part of a batch) and the physical isolation of these nuclear materials in a container which cannot be tampered with without

external evidence. In practice, this is done by using seals on suitable containers, attached according to specific procedures.

Surveillance is a technique designed to attain similar objectives using a series of physical observations on the controlled materials: in this way assurance can be given that the materials do not leave their assigned location.

The use of this technique obviates the need for the continuous presence of an inspector on site. The instruments used may consist of photographic or TV cameras or any other recording devices, conceived specially for the solution of particular problems.

It is important that the content of paragraph (d) of Article 7 be clear: "containment and surveillance measures, in accordance with the modalities agreed upon with the plant operators." This phrase may be reasonably interpreted by the two following statements:

- The containment devices shall not jeopardise safety nor preclude investigations by the Member State's safety authorities and may be broken in case of need, provided the Commission is informed immediately.
- The Commission's rights concerning containment and surveillance are not subordinate to any agreement of the operator.

Article 7 clearly states a right of the operator: his agreement is required on the techniques and procedures relevant to containment and surveillance operations. However, this right must not conflict with the Commission's right to choose and use the appropriate methods for application of safeguards.

6. PSP - Analytical Samples for Safeguards. This chapter of PSP is introduced by paragraph (e) of Article 7, which clearly states another right of the operator. The management of a plant has the right to prevent any person not under its authority from handling the nuclear materials for which it is responsible. This right is, however, limited by the control authority's right of verification; the nuclear materials must be presented to the inspectors on request but all handling of such materials must be agreed upon with the persons responsible. This is particularly applicable to sampling operations which may be required for destructive analysis. The physical operations are carried out by the personnel of the installation under the control of the the inspectors. These samples may be different from those taken for normal management operations.

For those installations in which sample taking for safeguards is a foreseeable operation, the PSP will include the relevant criteria and procedures.

7. PSP - Financial Aspects. The last paragraph of Article 7 states that: "The Commission will reimburse the person or undertaking concerned the cost of those special services which are provided for in the 'particular safeguard provisions,' or which are provided because of a special request of the inspectors and on the basis of an agreed estimate. The extent and modality of the reimbursement will be fixed between the parties concerned and will be reviewed periodically as necessary."

To amplify this text, the Commission has declared its readiness to pay the following:

- The rent of office space allocated to the Inspectors as well as the rent of suitable space for the Commission's own measuring equipment.
- The cost of installing an external telephone line and its rental as well as the cost of telephone communications made by the inspectors.
- The expense of the use by the inspectors or on their behalf of the operators' measuring equipment.
- The value of the material taken as samples for safeguards purposes only, on the basis of the price on the day of sampling.
- The cost of transportation and analysis of samples except where a sample is the subject of arbitration in which case the cost will be shared.

E. Ore Producers, Carriers and Intermediaries

The Regulation describes not only the duties of the persons or undertakings mentioned in Article 1, but also those of other categories of persons involved in the nuclear material cycle, namely ore producers, carriers and intermediaries. The provisions of this part of the Regulation have their legal foundation in the Euratom Treaty and are peculiar to it. They help to give the international Community system a more general, complete and effective character.

1. Ore Producers (see Articles 29 - 31). They must maintain an account of the quantities of materials produced,

accumulated as stocks, and shipped. They are obliged to provide the Commission with a separate evaluation of the amounts dispatched no more than once a year. Furthermore, in case of exports of ore outside the Community, the Commission must be suitably informed.

2. Carriers (see Articles 32, 33). The development of the nuclear industry involved a significant increase in the quantities of materials controlled and in the number of related transport operations. The risk of diversion has become greater and it has been necessary to grant to the Commission the right to perform inspections on the carriers who are temporary holders of the nuclear materials. Therefore, the carriers are obliged to accept or hand over nuclear materials subject to safeguards only on receipt of a duly signed and dated receipt.

3. Intermediaries (see Article 34). The motives given for the obligations imposed on the carriers apply equally to the provisions concerning the intermediaries. In fact, a nuclear material trade has been created by companies which have no real industrial activity, being interested only in the commercial aspects of this particular market. In these circumstances, it has become essential that such persons or undertakings keep proper records of their activities and that such records may be made available, on request, to the Community control authority for any possible enquiry.

F. Particular Safeguard Obligations (see Articles 9 and 10)

In general terms these obligations may be described as restrictions on the utilization of nuclear materials or as particular procedures for the application of safeguards on these materials which are supplied by a state not belonging to the Community.

The particular conditions are required by the supplier countries and accepted or granted by the Community. Usually such commitments are a condition for further supplies of materials to the nuclear industry of the Community. It is the Community's duty to ensure that the commitments are fulfilled.

The most important consequence of these types of engagements is that the nuclear material submitted to a "particular obligation" must be accounted for in such a way that in the following returns a separation "per obligation" occurs:

- initial inventory
- Inventory Change Reports (ICR)
- Physical Inventory Listing (PIL)

Under specific conditions the separation in the accounts does not preclude a physical mixing of materials under different obligations.

At present the most important particular obligations to be met may be divided into two groups:

1. The obligations relevant to materials supplied to the Community in application of cooperation agreements with the specific countries: e.g., USA, Canada, Argentina, Brazil.
2. The more general obligations of "pacific use," such as that undertaken with the NPT in the non-nuclear weapon states. This group could include other pacific

commitments imposed by an authority other than the Community, e.g., by a Member State.

G. Use

The notion of use, in relation to safeguards, is already present in the Rome Treaty (Article 77). It also appears in all the supply contracts, as indicated in Article 60 of the Treaty of Rome.

The practical requirements of the Regulation concern the registration in the accounts of the information already known or determinable and the reporting of such information, when indicated by Articles 13 (initial inventory), 14 (ICRs) and 16 (PILs).

The definition of use includes two elements:

- the use intended or made in the installation, e.g., fuel fabrication, conversion, storage, energy production, Pu production, etc. This element is relevant to the features of the installation as described in the "basic technical characteristics."
- the specific final use, e.g., loading of reactor X, research work in the field of ..., basic working stock of the installation, stock for future work without definite final use (at present), etc.

H. Materials in Nuclear Weapons States

Article 35 takes into account the existence, as foreseen by the Treaty, of nuclear materials used to meet defense requirements; only 2 member-states (France and the United Kingdom) are nuclear weapon states, all the others, by virtue of their accession to the Non Proliferation Treaty have renounced the use of nuclear materials for weapons research. Article 35 inter alia defines a category of material which being free of any peaceful use obligation is "liable to be assigned to meet defense requirements" and provides for the appropriate application of safeguards to it.

VI. THE NON-PROLIFERATION TREATY AND THE AGREEMENTS WITH THE IAEA

A. Background

Art. III of the N.P.T. requires the application of IAEA safeguards to all non nuclear weapon states party to the Treaty, and foresees, furthermore, that these requirements can be met by the states either individually or together with other states. An agreement was therefore concluded in 1973 between the IAEA, the European Community (represented by the Commission) and its seven non-nuclear weapon Member States. It entered into force in February 1977 after ratification by the Member States concerned and after the Commission had established the necessary legal instruments for its implementation.

This agreement derives closely from the model agreement (INFCIRC 153) applicable to all safeguards agreements under the Non Proliferation Treaty, but contains certain specially-drafted articles and in particular a "Protocol" which take into account the particular multinational nature of Euratom Safeguards and the overall relationship between the two safeguards authorities.

The Agreement defines the mutual obligations undertaken by the Community (and its signatory member states) and the IAEA.

The dispositions of the Agreement are not, as such, directly applicable to the operators of nuclear facilities: it is the Community Regulation 3227/76 which defines all the operator's duties. This instrument allows the Community to fulfill the commitments undertaken with the Agreement.

The "Agreement" actually consists of a set of documents, namely:

1. The Agreement "itself" which contains the general principles, the criteria and the practical outlines for the application of safeguards to nuclear materials. It contains 98 articles put together in two parts. The first gives the basic principles, the second gives an outline of the implementation system.
2. The "Protocol." It is a document which specifies the conditions and the means for the necessary IAEA-Commission cooperation in the implementation of the Agreement's provisions.
3. The "Subsidiary Arrangements." Under this title a set of heterogeneous documents is collected. These documents contain general rules and practical procedures for executing the Agreement, in terms applicable to all peaceful nuclear activities in the signatory Member States of the Community, specifying quantities and schedules.

The Agreement and the Protocol are documents which have been ratified by the national parliaments before they enter into force. Any modification of such treaties implies the agreement of all the involved parties. With the same ratification procedures the SA may be defined as the implementation rules which allow the practical execution of the requirements of the Agreement. They concern the authorities responsible for safeguards implementation, that is, the IAEA and the Commission. They do not need any ratification of the Member States and may be updated by faster procedures. Nevertheless, all the Member States concerned have formally approved the introductory and general parts of the SA. The SA is a document which, by agreement between the parties, is considered as confidential; however, those parts which are of a general character and which follow the Agreement clearly may be described without difficulty.

B. Subsidiary Arrangements

The SA's are constructed as follows:

Introduction I: "Rules and Methods" (R&M) for estimating Actual Inspection Effort for Routine inspection activities of Community (ARIE 1) and of IAEA (ARIE 2). The general rules are followed by a series of "Examples" of application of such rules to some typical nuclear facilities.

Introduction II: "Coordination Arrangements" (with reference to Protocol Articles 19 and 20) for different types of facilities.

Introduction III: "Form and Format" specifications for the reports that the Community must regularly submit to IAEA, as required by Article 9 of the Protocol.

General Part: The content is subdivided in ten "codes."

The most interesting, for the understanding of the "Information System" is "Code 10," which provides explanations of the content of reports. These reports are the ones which the Community must supply to the IAEA. They are not the same as those the Community will receive from the facility operators, in accordance with the Commission Regulation 3227/76.

Annex I: List of the Facilities and the MBAs submitted to safeguards under NPT in the Community. (To be updated when the necessity arises.)

Annex II: Collection of "Questionnaires" to serve as a guideline for the provision of "Design Information (DI, in the following), pursuant to Article 2 of the Protocol.

"Attachments" Set: A separate Attachment to the SA for each facility (and each MBA outside facilities) in the signatory Member States must be completed.

The Facility Attachment (FA) is a document detailing safeguards application for each facility subject to the Agreement. It contains information such as design characteristics, quantity, quality and location of materials, recording and reporting requirements, normal Community and IAEA inspection procedures, etc. It is important to stress that the FA is a document concerning directly only the IAEA and the Community. The Community discharges the commitments undertaken with this document, by the obligations imposed on the Operators, via the

Community Regulation 3227/76, and in particular by means of the Particular Safeguard Provisions mentioned therein.

C. Euratom/U.K./IAEA Agreement

The United Kingdom (UK), the Community and the IAEA in 1976 signed an agreement which foresees the submission to the NPT safeguards of all the civil nuclear materials in the UK. The UK is designated in accordance with the NPT as a "Nuclear Weapon State," so that its nuclear material is not obligatorily submitted to NPT safeguards. However, the UK made a voluntary offer of submission "to encourage widespread adherence to the [NP] Treaty by demonstrating to Non Nuclear Weapons States that they would not be placed at a commercial disadvantage by reason of the application of safeguards pursuant to the [NP] Treaty. This Agreement is not yet operational; at the time of writing the draft Subsidiary Arrangements are awaiting the approval of the Council of Ministers.

The essential differences between this Agreement and that relating to the 7 Non-Nuclear-Weapon States are

a) that the UK has always the right, subject to an advance notification, to withdraw any of its materials from the scope of the Agreement for national security reasons, and
b) that the IAEA obligations to ensure that safeguards are applied affects only those nuclear materials which are in those facilities "designated" from time to time by the IAEA within the United Kingdom "Facilities List."

D. Euratom/France/IAEA Agreement

France, the Community and the IAEA in 1979 signed an agreement which provides for the application of Agency safeguards to certain nuclear materials in France. France is not a signatory to the NPT, but is a Nuclear Weapon State. In most respects the working of the agreement is close to that of the UK/Euratom/IAEA Agreement. The most notable differences relate to the designation, by France, of the nuclear materials that are to be subject to the Agreement and to the absence of any requirement of "national security reasons" for the withdrawal of materials from the scope of Agreement. The Agreement has not yet been ratified.

E. Implementation of the Non-Nuclear-Weapon-State Agreement

At present time 200 Facility Attachments (or Attachments for locations outside Facilities) are agreed between the Community and the IAEA and are in force. There are a further 16 Attachments under discussion which relate either to recently declared facilities or to special cases for which an internationally agreed scheme of verification does not exist yet.

Each month Euratom sends the IAEA all the reports foreseen, and inspections are carried out according the provisions of the individual Facility Attachments. For some installations where significant quantities of enriched uranium or plutonium are processed the inspections are carried out "jointly" by a single team comprising inspectors from the two organizations.

F. Agreements With Third Countries

Euratom has two main agreements for cooperation in the field of nuclear energy, with the USA and with Canada. Those agreements cover various aspects of which the most important are: supply of material, supply of equipment, and the safeguard conditions to be applied. The responsibility for safeguards is placed upon Euratom; some provisions exist for periodic consultations in order to ensure that the safeguard standards are being maintained at the international level. It is important to note that as far as the agreement with USA is concerned it has now incorporated all the bilateral agreements that the USA had earlier made with the European countries, at the moment of expiry of each in turn. By this process of "folding-in" to the USA-Euratom Agreement, the American inspectors no longer inspect any of the nuclear materials supplied by them; they have been replaced by the Euratom inspectors by virtue of their supranational status.

VII. EXTENT AND ORGANIZATION OF THE EURATOM SAFEGUARDS SYSTEM

A. Quantity and Distribution of Materials

The rounded quantities of materials under Euratom safeguards are currently as follows:

Plutonium	30 tonnes
Highly Enriched Uranium	13 tonnes
Low Enriched Uranium	10 000 tonnes
Natural Uranium	28 000 tonnes
Depleted Uranium	14 000 tonnes
Thorium	1 300 tonnes
(Heavy Water	440 tonnes)

These stocks are distributed through the nine Member states in about 450 installations of all sorts of different categories, from research laboratories, storage facilities and non-nuclear users to reactors, fuel conversion, enrichment and fabrication plants and reprocessing plants.

All the current industrial-scale fuel cycles are represented, e.g., natural uranium gas/graphite, low enriched uranium advanced-gas, boiling- and pressurized-water, heavy water, materials-testing and fast reactors, together with the necessary associated plants for fuel production and reprocessing. More limited facilities exist for other less fully developed cycles, e.g., the pebble-bed high temperature gas concept.

It may be worth mentioning that the enrichment plants cover both diffusion and ultra-centrifuge technologies, and that the reprocessing plants (omitting laboratory-scale experiments) deal with natural, low-enriched, high-enriched, and mixed oxide fuels in metal, alloy or oxide forms.

B. Staffing

The Safeguards Directorate is located in Luxembourg, and has a staff of about 150 people. They are nationals of all nine Member States of the Community, and are all permanent European civil servants. Because of the confidential nature of much of their work, each member of the staff has to have a specific clearance for access to classified information. Since Luxembourg is also the base for some 1500 other Commission employees, the Directorate can draw on the common local support services, e.g., administration, personnel and translation services. The Safeguards Directorate is part of the Directorate General n° 17-Energy, the remainder of which is located in Brussels.

Within the Directorate there are four Divisions, of which two are responsible for inspections, one for accountancy, and one for conceptual aspects and technical support. The latter deals with technical development, establishment of procedures, relations with external organizations and governments and the technical activities in support of inspections, such as the organization of the chemical and/or isotopic analysis of samples taken during inspection, preparation of seals, cameras, TV systems, etc. The distribution of responsibilities between the two inspection divisions is based partly on territorial considerations and partly on the technical nature of the installations concerned.

C. Accountancy

The main task of the accountancy division is the routine processing and verification of the monthly declarations made by the installations and to establish the reports as required by the IAEA. The system has been computerized since 1960. The inevitable errors and misunderstandings in the declarations made by the installation operators require thorough checking and investigation procedures applied systematically. Currently each month up to 20000 entry lines, each with about 15 items of information, are received and processed. Some of this information is not relevant to IAEA safeguards, for example the data on materials in France, or before the starting point of Agency safeguards, and the data on particular safeguarding obligation (origin-accounting), but the remainder is, after the internal checking and "cleaning up" procedures, prepared for transmission in the appropriate format to the IAEA.

Many of the routine verifications carried out by Euratom, which ensure the accuracy, continuity, self consistency, completeness and timeliness of the accounting system, seem to be obvious. But, when one appreciates the large amount of data reported every month to Euratom, one will see that these verifications have to be carefully organized and clear internal instructions and responsibilities must exist to ensure that they are carried out properly.

The first and most basic accounting verification is to check that all reports are received and on time.

During computer processing, arithmetic checks are carried out. The reported monthly book inventory is compared automatically with the book inventory calculated by the computer. Every inconsistency is signalled and immediately followed up.

A further check, which is also extremely important, is the check on all transfers which result in material either entering Euratom's control or leaving it--in other words, imports, exports, etc.

The IAEA is in the fortunate situation that the above-mentioned verifications are already carried out by Euratom and, consequently, the follow-up work need not be repeated by the IAEA. The quality of the reports submitted to the IAEA is therefore higher than the quality of the reports submitted originally to Euratom before the corrections have been carried out.

D. Inspections

The Commission has, at the time of writing, 87 inspectors, of whom a large proportion are permanently allocated primarily if not exclusively to inspection duties.

Apart from the general provisions of the Treaty there are no specific regulations concerning the performance of inspections. Naturally internal rules have been established, but no external limitations or commitments with respect to states or installations exist.

The basic routine inspection activities consist in the verification of the use and the fulfillment of supply obligations and external commitments, verification of the operator's accountancy and physical verification of the flows and inventories of materials. The use by the inspectors of our own measuring equipment, mostly for non-destructive determinations, has been a feature for many years, and is continuously increasing, both in scope and in intensity.

In ections are carried out in installations in all the Member states of the Community. For the installations in the 7 Non Nuclear Weapon States party to the 1973 Agreement with the Agency, Facility Attachments have been agreed which fix the number and scope of the inspections to be performed by Euratom and by the Agency. (Agency inspections must be performed at the same time as Euratom inspections, and the Agency is required, subject to certain provisions protecting the Agency's right to make independent measurements and observations, to implement its inspection activities through observation of the Euratom inspection activities). For some installations dealing with plutonium, highly enriched uranium or the enrichment of uranium, it has been agreed that the inspections are carried out jointly (i.e., by Joint Teams of Euratom and IAEA inspectors) in order to ensure the most effective use of the limited inspection manpower available on either side, while minimizing the burden to the operator of the application of safeguards. It is similarly envisaged that for the facilities in the UK designated for inspection by the IAEA under the 1976 Agreement Euratom and the IAEA will again apply Joint Team inspections in appropriate cases.

E. Technical Support

The inspection activities require an infrastructure designed to resolve any problems arising in connection with their performance. Falling within this definition is a wide range of activities such as the definition of strategies at all levels, the preparation of procedures, the maintenance of equipment (both for measurement and for surveillance), data reduction, the organization of the analysis of samples, and the provision, identification and reidentification of seals, etc. These tasks are carried out within the Directorate by staff who in many cases are inspectors and therefore involved in the theory, the practice and the support of inspections.

However, for work falling more in the domain of research and development, the Safeguards Directorate is fortunate in being able to call on the services of the Joint Research Centre of the European Communities. The J.R.C. has within its overall programs a section dealing with safeguards research and development, which is mainly carried out in the Ispra centre (Va-Italy), and which includes systems analysis, development of instruments for non-destructive assay, chemical and isotopic correlations, development of seals and sealing techniques, and training.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #8a: IAEA INTERNATIONAL SAFEGUARDS

SPEAKER: Carlos Buechler

International Atomic Energy Agency
Vienna, Austria

Wednesday, May 28, 1980
2:00 p.m.

BIOGRAPHY

Education: Ingeniero en Telecomunicaciones (communications engineering) University of Buenos Aires, 1953.

Present Position: Head, Section for Standardization and Administrative Support, Department of Safeguards, International Atomic Energy Agency.

Past Positions: Assistant in Electrical Engineering at Argonne National Laboratory, USA, 1956-1961. Twenty-one years in International Safeguards.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #8b: IAEA INTERNATIONAL SAFEGUARDS

SPEAKER: Bernardino Pontes

International Atomic Energy Agency
Vienna, Austria

Wednesday, May 28, 1980
3:15 p.m.

BIOGRAPHY

Present Position: Head, Safeguards Training Unit, International Atomic Energy Agency, Vienna

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #8c: IAEA INTERNATIONAL SAFEGUARDS

SPEAKER: Gordon Hough

International Atomic Energy Agency
Vienna, Austria

Wednesday, May 28, 1980
4:30 p.m.

BIOGRAPHY

Present Position: Head, Section for Data Evaluation Services, Division of Safeguards Information Treatment, International Atomic Energy Agency.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #8: IAEA INTERNATIONAL SAFEGUARDS

IAEA International Safeguards background, objectives, requirements, inspection procedures, and safeguards implementation under INFCIRC-66 and INFCIRC-153 will be developed in depth. Emphasis will be placed on clarifying the distinction between safeguards system characteristics required to satisfy IAEA requirements and those characteristics intended to meet other domestic system objectives.

The division of topics among the three lectures is as follows:

Part I
IAEA General features; Organization, Structure
Requirements (INFCIRC-66; INFCIRC-153)

Part 2
Negotiation of Agreements and Facility Attachments
Design Information Questionnaire - IAEA Use and Verification
IAEA Inspection Procedures
Evaluation, Assessment; Safeguards Implementation Reports

Part 3
IAEA Reports and Records (Compatibility problems, Stratification, Form and Format, Sources of Error, Magnetic Tapes, Corrections)

After the session, participants will be able to

1. a. Understand the basic objectives of Safeguards and the legal basis for their application.

   b. Have a basic notion of the Safeguards provisions in the fundamental documents that are relevant: the Agency Statute, INFCIRC 66, and INFCIRC 153.

c. Know the different types of Safeguards Agreements and the main difference between them.

d. Understand the role of and know the structure and basic elements of Subsidiary Arrangements and Facility Attachments.

e. Understand the basic technical rationale of the Agency's Safeguards System and the factors affecting its effectiveness.

2. a. Understand the whole framework of the Agency Safeguards' procedures to achieve the end point (statements of activities and conclusions).

b. Know the provisions of information provided by the State and its verification by inspections.

c. Recognize the relevant activities and their scope in the performance of an inspection.

3. a. Understand the purposes of IAEA Examination of Records.

b. Know the reasons and procedures for stratification of inventory and inventory changes.

c. Know the kinds of information to be recorded in records and the information needed by the inspector.

d. Understand the basis for a measurement-control program that enables determination of the accuracy and control of the measurement methods used to establish a material balance.

e. Know features of a facility records system that will speed up inspection activities and minimize interference to facility operations.

SESSION 8a: IAEA INTERNATIONAL SAFEGUARDS

OBJECTIVES, DIVERSION OF NUCLEAR MATERIAL, AND THE IAEA SAFEGUARDS SYSTEM

C. Büchler
International Atomic Energy Agency

I. OBJECTIVES OF IAEA SAFEGUARDS

A. Introduction

Nuclear and non-nuclear material, services, facilities, equipment and information which are to be used for legally defined purposes may be deliberately diverted from these purposes. The actions aimed at the detection and deterrence of this diversion are known as safeguards.

Potential divertors are facility operators, individuals or groups of individuals and States. IAEA safeguards are aimed at the timely detection of diversion in or by States having undertaken to accept safeguards in accordance with an agreement between the IAEA and the State and at the deterrence of such diversion by the risk of early detection by the IAEA.

B. Safeguards in the Statute of the IAEA

The Statute authorizes the IAEA "to establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy."[1] The Statute, therefore, limits the application of safeguards to IAEA sponsored projects and to activities for which a specific request is made by a State.

The IAEA shall, according to the Statute,[2] enter into an agreement with the State or group of States submitting a project, which agreement shall include undertakings that "the assistance provided shall not be used in such a way as to further any military purpose"; and that "the project shall be subject to the safeguards provided for in Article XII, the relevant safeguards being specified in the agreement."[3]

Furthermore, the Statute specifies the IAEA safeguards rights and responsibilities concerning projects and arrangements.[3] These rights and responsibilities include, inter alia, the use of inspectors "who shall have access at all times to all places and data...as necessary to account for source and special fissionable materials supplied and fissionable products and to determine whether there is compliance with the undertaking against use in furtherance of any military purpose."[4]

C. Project Agreements, Safeguards Transfer Agreements and Unilateral Submissions to IAEA Safeguards

Since 1961 the IAEA has entered into "projects agreements" for the supply of materials, equipment and facilities made available by or through the IAEA; "safeguards transfer agreements" in which the States transfer to the IAEA their safeguards responsibilities set forth in their cooperation agreements; and agreements for "unilateral submissions" by a State to IAEA safeguards of certain facilities, nuclear material or all the State's nuclear activities.

All such agreements are based on the safeguards system which the IAEA set up in 1961,[5] extended in 1964,[6] revised in 1965[7] and extended in 1966[8] and in 1968.[9] This system[5–9] does not specify further than the Statute does[4] either the objective of safeguards or the conclusion of the IAEA verification activity in stipulating that nuclear material, facilities and equipment shall not be used to further any military purpose and that the IAEA shall determine whether there is compliance with the terms of the agreements. The undertaking by a State has been explicitly stated in "safeguards transfer agreements" concluded since 1975[10,11] as not to use nuclear material, facilities and equipment for the manufacture of nuclear weapons or to further any other military purpose, or for the manufacture of any other nuclear explosive device.

D. Safeguards Agreements Pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) entered into force in March 1970.[12] Each non-nuclear weapon State party to the Treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the IAEA in accordance with the Statute of the IAEA and the IAEA safeguards system, for the exclusive purpose of verification of the fulfillment of its obligations assumed under the Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices.[13] Procedures for the safeguards required shall be followed with respect to all source or special fissionable material whether it is being produced, processed or used in any nuclear facility or is outside any such facility. The safeguards required shall be applied on all source or special fissionable material in all peaceful nuclear activities within the territory of such a State, under its jurisdiction, or carried out under its control anywhere.

Each State party to the Treaty also undertakes not to provide source or special fissionable material, or equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear weapon State for peaceful purposes, unless the source or special fissionable material is subject to the required safeguards.[14]

At the time of the entry into force of the NPT, most of the governments concerned expressed the view that the IAEA safeguards system was insufficiently defined. All members of the IAEA were therefore invited to take part in a specially convened "Safeguards Committee." The Committee agreed on "the structure and content of the agreements between the Agency and States required in connection with the Treaty on the Non-Proliferation of Nuclear Weapons,"[15] which has served as a basis for every agreement concluded in connection with the NPT.

The basic undertaking by the State in NPT safeguards agreements is to "accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices."[16]

The objectives of safeguards are further defined in these agreements to be the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."[17] The inclusion of the expression "for purposes unknown" is very important for the practical application of safeguards for it means that the IAEA does not have to attempt to determine the use to which diverted material is put and, in particular, does not have to determine whether diverted nuclear material is for "the manufacture of nuclear weapons or of other nuclear explosive devices." In addition, it is not an objective of IAEA safeguards to determine who is responsible for any diversion.

The agreements provide for "the use of material accountancy as a safeguards measure of fundamental importance, with containment and surveillance as important complementary measures"[18] and also provide that "the technical conclusion of the Agency's verification activities shall be a statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."[19]

E. Implementation of Safeguards by the IAEA

The IAEA safeguards system is laid down in two IAEA documents, INFCIRC/ 66/Rev. 2 [9] and INFCIRC/153.[15] The first document forms the basis for bilateral agreements, transfer agreements and unilateral submissions under which equipment, facilities, nuclear material, other material and information are subject to safeguards. The second document forms the basis of all agreements required by Article III.I of the NPT, under which all nuclear material in all peaceful nuclear activities of a State is subject to safeguards. INFCIRC/153 obliges the IAEA to draw from its verification activities a technical conclusion in respect to nuclear material for each material balance area. INFCIRC/66/Rev. 2 does not include the required specifics of a conclusion, but the IAEA is obliged by the Statute to make a determination of compliance and, where non-compliance has been concluded, to report to the Board of Governors. INFCIRC/66/Rev. 2 provides the IAEA with means to draw in respect to nuclear material the same type of technical conclusion as required by INFCIRC/153. The IAEA has to judge in each particular situation whether the application of its nuclear material verification procedures permits it to fulfill the responsibility of safeguarding equipment, facilities, non-nulcear material or information.

Implementation of nuclear material safeguards requires quantification of the objectives for each situation. To provide guidelines for the implementation requires identification of the possible strategies that a State may adopt for diverting nuclear material and specification of the measures that the IAEA must employ in its safeguards system in order to be able to counter successfully these diversion strategies. These subjects are treated in the following sections.

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16. INFCIRC/153, Article I.

17. INFCIRC/153, Article 28.

18. INFCIRC/153, Article 29.

19. INFCIRC/153, Article 30.

II. DIVERSION OF NUCLEAR MATERIAL

A. Introduction

In the context of IAEA safeguards, the State with its corresponding capabilities and resources is considered as the potential divertor and the probability of attempted diversion is considered small but finite. The purpose of diversion is assumed to be the acquisition of nuclear material for uses proscribed by the relevant safeguards agreement.

B. Diversion Strategies

The plans for diverting nuclear material and for either delaying the detection of the diversion or avoiding it are known as diversion strategies.

Diversion strategies could involve a single facility or a number of facilities cooperating in the diversion and its concealment. Diversion could involve material already in a form suitable for the intended use or in a form requiring further processing before such use. This further processing could be undertaken immediately or the diverted material could be stockpiled for processing and use at a later time. The divertor may attempt to use safeguarded facilities to process material which has been diverted at another safeguarded facility, or material which either is at the starting point of safeguards or has already undergone some processing and which must be under safeguards but has not been declared by the State. Such an attempt would provide the IAEA with a chance to detect at a facility material which had not previously been in a safeguarded facility or material which had been previously diverted.

The material might be diverted in either a single removal or repeated removals. Immediate detection by the IAEA can only be possible if it applies strict containment and surveillance measures. Verification of the physical inventory and of the material balance provides for a delayed opportunity for detection of diversion.

To conceal the removal of nuclear material the divertor may present evidence that the material:

(a) was never received at the facility in question;

(b) was shipped to some other facility or facilities;

(c) was discarded or accidentally lost; or

(d) is still present at the facility:

- (i) with complete items missing;
- (ii) with part of the items missing;
- (iii) with portions of materials from all items missing;
- (iv) with a combination of (i), (ii) and (iii);
- (v) by substituting, for the diverted material, non-nuclear material or material of lesser value to the divertor;
- (vi) by presenting material for counting more than once;
- (vii) by borrowing the needed quantity of material from another facility and returning it after inventory verification has passed.

The strategy of concealment that gives the inspector only one opportunity to detect the concealment may be called final concealment, as opposed to temporary concealment. The recording of fictitious discards is an example of final concealment. If the fictitious discard is not detected at the time of the discard itself, it will never be detected, because no second opportunity for verification will exist. The falsification of inventory data, in contrast, is an example of temporary concealment and transfers the diversion into the next material balance period, where it has a second chance of being detected. In temporary concealment the facility operator must continue to attempt to conceal the removal until he can achieve final concealment.

1. Falsification of Records and Reports

The concealment of the removal of nuclear material which had previously been included in the records and reports available to the IAEA would presumably involve some falsification of these documents as part of the divertor's attempts to conceal the shortage from the IAEA and, in particular, to avoid detection by audit. Such falsification can be classified as understatements or overstatements of inventory or flows and introduction of "mistakes" in the transcription of data or in calculations.

In cases where the facility receives material from unsafeguarded facilities, the operator may understate receipts by not recording all receipts or by recording smaller than actual quantities for some receipts. Another possibility would be to arrange for a receipt to arrive just prior to a physical inventory to replace material already removed and to record the transfer as a receipt which occurred after the inventory.

In cases when the facility ships material to facilities which are not subject to IAEA safeguards, the operator may record non-existing transfers. Other possibilities would be to record measured discards in excess of those which occurred or to record shipments as having occurred just prior to the physical inventory taking, but hold the material and ship it after the inventory.

There are many possibilities for the falsification of records by the introduction of "mistakes": recording a number and reporting a different one, recording correctly a series of numbers and recording an incorrect total, recording a correct net weight and analysis and recording an incorrect total, etc.

2. Deceiving IAEA Measurements

Concealment strategies could also involve attempts to deceive IAEA measurements with respect to either the completeness or the correctness of the measurements. Examples are partial or periodic bypassing of flow key measurement points, alteration of containers, biasing of instruments, and biasing of sampling devices.

3. Declaring Diverted Material as MUF

A divertor could choose to divert material without alteration of the inventory and inventory change data and allow the removal to be shown as MUF. This strategy may, or may not, be supported by inflation of the measurement uncertainties and might be supported by explanations designed to portray the MUF as being due to legitimate causes.

C. Importance of Diversion

The importance of the diversion depends on the type and amount of the diverted material. Materials, e.g., plutonium and highly enriched uranium, which are of immediate use for nuclear explosive devices represent a greater hazard than does material which requires a lengthy and complex process to be used for these devices.

Rough estimates of the times required to convert different materials to material suitable for nuclear explosive devices are given in Table 1. The times listed in Table 1 are dependent, among other factors, upon the amount of materials involved and the capabilities of the facilities carrying out the processing. If the necessary processing is carried out in a large unsafeguarded facility, the shorter times in each range would apply. If done in a large safeguarded facility by unreported introduction and removal of the material at less than full capacity rate, the intermediate times in each range might apply. If the processing is carried out in small unsafeguarded facilities or activities, the longer times would apply. These times provide the basis for the requirements for the timeliness of detection by the IAEA of diversion and, hence, for the frequencies of verification by the IAEA of its containment and surveillance measures and of physical inventories.

III. THE IAEA SAFEGUARDS SYSTEM

A. Introduction

The IAEA safeguards system must enable the IAEA to verify that a State has complied with its undertaking as specified in the relevant safeguards agreement. The safeguards responsibilities and rights of the IAEA can not, therefore, be delegated to the State or to any organization to which the State has delegated the State's responsibilities. The IAEA system has been conceived to ensure the timely detection of diversion that might be attempted by the wide range of strategies described in Section II. For these reasons the IAEA must verify the completeness, formal correctness and validity of the information (including all records and reports) made available by the State, regardless of the nature or level of the verification activities carried out by the State.

TABLE 1

IMPORTANCE OF DIVERSION (a)

Required conversion of nuclear material to the form suitable for the manufacture of nuclear explosive devices	Material form	Approximate range of times required to convert nuclear material to the form suitable for manufacture of nuclear explosive devices
Physical change; or chemical and physical change, but no purification	Plutonium and highly enriched metal, oxide or solution	Days to weeks
Chemical and physical change with purification	Irradiated fuel, radioactive solution, cold scrap	Weeks to months
Isotopic, chemical and physical change	Natural and low enriched	Less than one year

(a) Based on the approximate times required to convert the material suitable to manufacture of nuclear explosive devices.

By means of its safeguards system, the IAEA shall be able to verify, in particular, that:

(a) the quantities of nuclear materials imported into a State, produced within a State or otherwise becoming subject to safeguards in any peaceful nuclear activity are not understated by the State;

(b) the quantities of nuclear materials on which safeguards are to be terminated, e.g., exports or consumption, are not overstated by the State; and

(c) physical inventories are not overstated by the State, at intervals appropriate for satisfying the requirement for the timely detection of diversion.

Essential elements of the IAEA safeguards system are:

(a) a Safeguards Agreement between the IAEA and the State, including Subsidiary Arrangements and Facility Attachments;

(b) provision by the State to the IAEA of all information relevant to the operator's accountancy, containment and surveillance of the material according to State's regulations, which must be in compliance with the terms of the Agreement; and,

(c) verification by the IAEA that the State is complying with the basic understanding as laid down in the Agreement.

The different types of safeguards agreements have been described in Section I.B and describes the operator's measures of accountancy, containment and surveillance. Sections C and D describe, respectively, the information to be provided by the State and the verification to be carried out by the IAEA.

B. <u>Accountancy, Containment and Surveillance of Nuclear Material</u>

Accounting for nuclear material is defined as the knowledge of the material's identity, composition, quantity and location. Agreements of the INFCIRC/153 type require that "the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards...".[1] They prescribe that the system shall be based on a structure of material balance areas, a measurement system, a records and reports system and a system of control by the State that the accounting procedures are being operated correctly. INFCIRC/66/Rev. 2 [2] does not refer explicitly to a State's system of accounting for and control of nuclear material or to some of the above elements of such a system, but it does prescribe the accounting and operating records to be kept by the State and the accounting and operating reports to be submitted by the State to the IAEA.

The undertaking by a State in an INFCIRC/153 type agreement requires the State "to accept safeguards..., on all source or special fissionable material...".[3] Such agreements also specify the starting point of safeguards[4] and the conditions for the termination of safeguards[5] and for exemptions from safeguards.[6] Similar provisions exist in the agreements of the INFCIRC/66/Rev. 2 type.

The basic principle of the accountancy system required by INFCIRC/153 is the operator's recording at the facility and the State's reporting to the IAEA, for each material balance area, initial inventories of nuclear material and subsequent inventory changes. Additions to and subtractions from the initial inventory yield the "book inventory,"[7] the amount of nuclear material which, according to the operator, is expected to be in a given facility or a given material balance area. Periodically, the facility operator takes a physical inventory[8] in the material balance area by measuring the nuclear material which "is" present. For facilities having nuclear material in unsealed bulk form, because of the measurement uncertainties, there is usually some difference between the book inventory and the physical inventory. There may also be discrepancies for other reasons, e.g., failure to measure parts of the inventory or an unmeasured loss of material. The difference between book inventory and physical inventory is the "material unaccounted for,"[9] abbreviated to "MUF." As a variable derived from measurements, MUF is, like the measurements themselves, subject to uncertainties.

INFCIRC/153 provides definitions for the fundamental concepts of material accountancy, namely: book inventory,[7] physical inventory,[8] material unaccounted for,[9] adjustment,[10] batch,[11] batch data,[12] correction,[13] enrichment,[14] inventory change,[15] key measurement point,[16] material balance area,[17] nuclear material,[18] shipper/receiver difference,[19] and source data.[20]

Containment, as employed by the State or the operator, is understood as the restriction of the movement of or access to nuclear material. Containment measures are used by facility operators for physical protection of the material, safety of personnel and conventience of operational procedures. In general, containment measures are not provided specifically for safeguards purposes, but their existence in a facility often simplifies surveillance for safeguards.

Surveillance means instrumental or human observation to indicate the movement of nuclear material. Surveillance may indicate the effectiveness of containment and, therefore, has for the operator the same use as containment.

Both containment and surveillance are, for the IAEA, important measures complementary to material accountancy.[21] They should not impose any physical restriction on the movement of or access to material; but they have to provide to the IAEA information as to whether such movement or access occurred while inspectors were not present, in order to preserve the integrity of prior measurements of nuclear material by the IAEA and to provide the IAEA with knowledge of material flows at important points in a fuel cycle.

C. Information

Both documents, INFCIRC/66/Rev. 2 and INFCIRC/153, require that the State:

1. provide the IAEA with information in respect to facility design features and other information relevant to safeguards;

2. arrange that records are kept in respect of each material balance area; and,

3. provide the IAEA with reports in respect of nuclear material based on the records kept.

INFCIRC/153 prescribes the required design information[22] and the required systems of records[23] and of reports.[24] Member States have further advised the IAEA on the detailed design information to be provided by the States.[25] The IAEA Secretariat has prepared design information questionnaires for different types of facilities.[26] The IAEA Secretariat has established model Subsidiary Arrangements and Facility Attachments,[26] which contain, inter alia, reporting forms and explanations for their use.[27]

D. Verification

Although INFCIRC/153 does not contain a formal definition of verification, it does specify the activities, including independent measurements, to be used by the IAEA for achieving verification and it does specify that verification applies to the location, identity, quantity and composition of all nuclear material subject to safeguards.[28,29,30]

Accordingly, the IAEA's verification process consists of:

1. Examination of the information provided by the State in:
   - (i) Design information;[31]
   - (ii) Accounting reports;[32]
   - (iii) Special reports;[33]
   - (iv) Amplification and clarification of reports;[24] and,
   - (v) Advance notifications of international transfers.[35,36]
2. Collection of information by the IAEA in:
   - (i) Inspections for verification of design information;[37]
   - (ii) Ad hoc and routine inspections;[38,39] and,
   - (iii) Special inspections.[40]
3. Evaluation of the information provided by the State and collected in inspections for the purpose of determining the completeness, correctness, accuracy and validity of the information provided by the State.

The purpose of inspections of facilities "to verify design information"[37] is to enable the IAEA to evaluate the validity of the design information made available to the IAEA. This verification is carried out with respect to design information submitted for existing and new facilities and for subsequent modifications of these facilities. The purpose of the examination of design information is:

1. to identify the features of facilities and nuclear material relevant to the application of safeguards to nuclear material in sufficient detail to facilitate verification;

2. to determine material balance areas to be used for IAEA accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories;

3. to establish the nominal timing and procedures for taking of physical inventory for IAEA accounting purposes;

4. to establish the records and reports requirements and records evaluation procedures;

5. to establish requirements and procedures for verification of the quantity and location of nuclear material; and

6. to select appropriate combinations of containment and surveillance measures and the strategic points at which they are to be applied.

Accounting reports provide information on the initial inventory,[41] inventory changes[42] and material balances.[43]

The ad hoc inspections by the IAEA are carried out in order to verify the information contained in the initial report and to identify and verify changes that have occurred since the date of the initial report. Ad hoc inspections are also carried out for the purpose of identifying and, if possible, verifying the quantity and composition of nuclear material involved in international transfers.[38] In the case of transfers out of a State, these inspections, including the affixing of seals by the IAEA, are to be carried out at the time the material is being prepared for shipping. In the case of transfers into a State these inspections are to be carried out at the time the material is unpacked.[44/36]

The purpose of routine inspections by the IAEA is:

1. to verify that the information contained in the reports submitted by the State to the IAEA is consistent with the accounting and operating records maintained by the State;

2. to verify the location, identity, quantity and composition of all nuclear material subject to safeguards; and

3. to verify information on the possible causes of material unaccounted for, shipper/receiver differences and uncertainties in the book inventory.[39]

Special inspections are to be carried out by the IAEA:

1. to verify information contained in special reports; and

2. to collect additional information when the IAEA considers that the information provided by the State and the information obtained through routine inspections are not adequate for the IAEA to fulfill its responsibilities.[40]

The activities of the IAEA in the course of ad hoc, routine and special inspections are in general for the purpose of collecting information whereby the IAEA can independently establish that the information provided by the State is:

1. complete in that it covers all nuclear material that has been present in the material balance area;

2. formally correct in terms of being free of mistakes;

3. valid with respect to the actual location, identity, quantity and composition of all nuclear material subject to safeguards; and

4. accurate in terms of the conformity of the measurement data of the State (random and systematic errors) with internationally accepted measurement accuracy.

These activities include: examining records, making independent measurements on all nuclear material subject to safeguards using IAEA equipment and also State's or operator's equipment by verifying its proper functioning, calibration and procedures; obtaining samples and ensuring their proper collection, treatment, handling and shipping; using and servicing IAEA surveillance equipment; affixing and removing IAEA seals; and using other objective methods which become available.[29,30] Containment and surveillance measures in particular are to be used to help ensure the completeness of flow measurements.[45]

The right of access,[46] frequency[47] and notice[48] of inspections, designation[49] and visits[50] of inspectors are provided for in INFCIRC/153. INFCIRC/66/Rev. 2[2] contains also similar provisions.

The IAEA shall "make every effort to ensure optimum cost-effectiveness"[51] and, in order to ensure it, should use, among other means," the concentration of verification procedures in those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made, and minimization of verification procedures in respect of other nuclear material on condition that this does not hamper the IAEA in applying safeguards."[52] Therefore, the statements on material unaccounted for and its limits of accuracy must not necessarily be based on equally intensive verification activities in all types of facilities or for all types of nuclear material. These activities must, however, in all cases enable the IAEA to satisfy the objective of safeguards, i.e., the timely detection of diversion of significant quantities of nuclear material."[53] In structuring its verification system, the IAEA takes into account not only whether material can be readily made into nuclear weapons or explosives but also the relationship between various parts of the nuclear fuel cycle. For example, although low enriched uranium cannot be directly fabricated into nuclear weapons, its value as a starting point for the production of plutonium or for further enrichment cannot be overlooked.

To achieve optimum cost-effectiveness while ensuring the capability to detect the range of diversion strategies identified in Section II, the IAEA's verification system involves two different types of approaches, depending upon the type of nuclear facility. For facilities in which nuclear material is produced, such as enrichment facilities and power reactors and the larger research reactors, and for chemical reprocessing facilities where the material produced in reactors is separated from the other components of the irradiated fuel, the verification of all flows is of critical importance. In other types of facilities, the primary inspection activity is inventory verification.

The technical conclusion of the IAEA's verification activities shall be "a statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."[54] It is important as a measure of the degree of agreement between the measurements of the operator and those of the IAEA and as a measure of the extent and the accuracy of the IAEA's measurements that the technical conclusion of the IAEA's verification activities includes the operator's MUF adjusted for any differences between the IAEA's and the operator's measurements and an estimate of the combined measurement uncertainties.

The IAEA shall inform the State of the results of inspection and the conclusions it has drawn from its verification activities in the State, in particular, by means of statements in respect of each material balance area.[55]

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1. INFCIRC/153 (Corrected) Article 7
2. INFCIRC/66/Rev. 2
3. INFCIRC/153 (Corrected) Article 1
4. INFCIRC/153 (Corrected) Articles 33, 34
5. INFCIRC/153 (Corrected) Article 35
6. INFCIRC/153 (Corrected) Articles 36, 37
7. INFCIRC/153 (Corrected) Article 102
8. INFCIRC/153 (Corrected) Article 113
9. INFCIRC/153 (Corrected) Article 111
10. INFCIRC/153 (Corrected) Article 98
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19. INFCIRC/153 (Corrected) Article 114
20. INFCIRC/153 (Corrected) Article 115
21. INFCIRC/153 (Corrected) Article 29
22. INFCIRC/153 (Corrected) Articles 42-45; 49-50
23. INFCIRC/153 (Corrected) Articles 51-58
24. INFCIRC/153 (Corrected) Articles 59-65; 67-69

25. IAEA Working Group Report on "Design Information Requirements for IAEA Safeguards," Safeguards Technical Report (STR), Rev. 1, December 1972.

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28. INFCIRC/153 (Corrected) Article 72

29. INFCIRC/153 (Corrected) Article 74

30 INFCIRC/153 (Corrected) Article 75

31. INFCIRC/153 (Corrected) Articles 43, 44, 49

32. INFCIRC/153 (Corrected) Articles 62-65, 67

33. INFCIRC/153 (Corrected) Article 68

34. INFCIRC/153 (Corrected) Article 69

35. INFCIRC/153 (Corrected) Article 92

36. INFCIRC/153 (Corrected) Article 95

37. INFCIRC/153 (Corrected) Article 48

38. INFCIRC/153 (Corrected) Article 71

39. INFCIRC/153 (Corrected) Article 72

40. INFCIRC/153 (Corrected) Article 73

41. INFCIRC/153 (Corrected) Article 62

42. INFCIRC/153 (Corrected) Articles 63, 64, 65

43. INFCIRC/153 (Corrected) Article 67

44. INFCIRC/153 (Corrected) Article 93

45. INFCIRC/153 (Corrected) Article 46 (b)(ii)

46. INFCIRC/153 (Corrected) Articles 76, 77

47. INFCIRC/153 (Corrected) Articles 78-81

48. INFCIRC/153 (Corrected) Article 83-84

49. INFCIRC/153 (Corrected) Article 85

50. INFCIRC/153 (Corrected) Articles 87-89

51. INFCIRC/153 (Corrected) Article 6

52. INFCIRC/153 (Corrected) 6 (c)

53. INFCIRC/153 (Corrected) 28

54. INFCIRC/153 (Corrected) 30

55. INFCIRC/153 (Corrected) 90

SESSION 8b: IAEA INTERNATIONAL SAFEGUARDS INSPECTION PROCEDURES

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The end result of all IAEA inspection procedures is a statement summarizing (a) the activities carried out and (b) the conclusions which have been drawn as a result of those activities. This statement is sent formally to the government of the country with which a safeguards agreement has been made and it also forms the basis for internal IAEA conclusions as to the effectiveness of its work. These conclusions are analyzed annually in the Safeguards Implementation Report (SIR) which is dealt with elsewhere.

It may seem paradoxical to start a lecture by talking about an end point but in fact it is logical since the whole framework of IAEA procedures is designed to achieve that end point. Without full appreciation of the end point and its importance the initial stages may make little sense and perhaps appear as no more than bureaucratic procedures.

The stages in reaching the statements of activities and conclusions can be summarized as follows:

1. Provision by the State of Design Information on facilities.
2. Examination by the IAEA of the Design Information to select a Safeguards Approach.
3. Agreement between the State and the IAEA on a Facility Attachment which lists the safeguards measures.
4. The provision of accounting reports by the State together with notices of international transfers.
5. Inspections to verify the information provided.
6. The evaluation of the information provided by the State and collected in inspections, for the purpose of determining the completeness, accuracy and validity of the information provided by the State.

Broadly speaking it will be seen that the stages fall into two groups--the provision of information and its verification by inspection.

The previous paper will have dealt with the procedures for negotiating the legal agreements leading to the Facility Attachments, and the following paper will deal in some detail with the accounting reports. The purpose of this paper is to cover the inspection or operational aspects.

The Operations Divisions of the IAEA, by which inspections are carried out, are organized into geographical regional sections. Within the sections the organization may be further subdivided into regions, in the case where a number of small countries are covered, or by function where only a few, but nuclear-wise important, countries are covered. Administratively, routine matters are handled by a so-called Country Officer who is the principal point of contact between the Agency and the representatives of a State. For matters which have a strong legal or political significance however such as the negotiation of Facility Attachments, a negotiating team is formed. This typically consists of the head of the regional section involved, a legal representative, an administrative specialist, to ensure that standard procedures and layouts are followed, a specialist from reports handling section and two other members from other regional sections to ensure that the negotiations are conducted fairly and equitably compared to those with other countries.

The Design Information which forms the starting point of the inspection chain is provided by the State in the form of answers to a Design Information Questionnaire (DIQ). There are several versions of this questionnaire depending upon the facility being dealt with but the basic structure is similar for all. Information is requested on the location of the facility, its use, throughput, its material accountancy procedures, its storage locations and the organization of responsibility for materials management.

A balance has to be struck between the need of the Agency to know as much as possible about the facility and the characteristic natural resistance of an operator to reveal more about his facility than he considers necessary.

The answers to the questionnaire may be discussed with the State representatives and supplementary information may be requested. The IAEA objective of getting this information is to determine how best the facility may be safeguarded from the point of view of the State fulfilling its international obligations. The State's internal safeguards system may, and does, have other interests and requirements such as the adequacy of physical protection. The Agency at this stage is concerned with the DIQ only as a stepping stone to the next stage--the agreement of a Facility Attachment.

From the DIQ, a breakdown into one or more material balance areas for accountancy purposes is selected together with key measurement points where inspectors may have access to material to weigh, take samples or carry out NDA measurements to verify the accounting statements of the operator. If appropriate, points where surveillance cameras or seals could be installed are identified. A figure of the number of man-days of inspection effort necessary is estimated and the procedures for recording and reporting all shipments, receipts and inventory of material are established. Eventually all this information is codified in the Facility Attachment.

Clearly to do this preliminary work adequately, it is impossible to rely upon the exchange of written information. The initial general safeguards agreement which precedes the negotiation of the Facility Attachment has provision for the carrying out of so-called "ad hoc" inspections. These are inspections necessary before the details of the facility attachment negotiations can be completed. They are used to verify the Design Information provided by the State and to give the basic knowledge of the plant which is necessary for intelligent negotiation. They are also used to establish the initial inventory for the start of safeguards. Once the Facility Attachment is agreed, the ad hoc inspections are replaced by routine inspections.

Routine inspections are carried out periodically with the objective of monitoring the flow of material in and out of a facility and periodically striking a material balance by verifying physical inventories. To do this properly requires careful preparation so each series of inspections is preceded by a planning phase. Within the inspectorate a standardized set of inspection practices has been set up for each type of facility. Before going out on an inspection visit an inspector is required to study the standard practices and draw up an Inspection Plan ensuring his intentions are in line with these standard procedures. The Inspection Plan will also list the dates of the last inspection, the period through which the book and records are to be examined, details of any NDA measurements, or samples to be taken and any containment or surveillance devices to be serviced.

At the facility the first activity is to examine the facility records to ensure:

1. adequate records are kept,

2. the records agree with reports to the IAEA,

3. the records are consistent with each other and with supporting documents such as shipping documents,

4. that an updated book value can be established for the nuclear material present. This updated book value is the essential figure around which the physical part of the inspection will be conducted.

For a full physical inventory verification the inspector will have expected the operator to have stopped production and as far as possible to have cleaned the plant out. Nuclear material should have been accumulated into a few previously agreed (in the Facility Attachment) key inventory measurement points. The material should have been stratified* and lists of the items in each strata should have been prepared by the operator to give to the inspector.

From these lists a statistical sampling plan will be drawn up to indicate how many samples need be taken for NDA or chemical analysis to meet the detection target for the inspection. This target is a figure chosen to be the maximum quantity of nuclear material that may be unaccounted for within a certain level of confidence (usually 95% confidence). Since such an objective implies a limit of accuracy, the verification procedures used in the inspection must also be aimed at establishing the operators measurement uncertainty.

All the inspectors' findings are embodied in working papers which are processed at Headquarters to result in an inspection report. This

*This term will be dealt with in detail in a later paper.

report is reviewed at successive levels within the IAEA. It is a technical report with technical conclusions. Subjective assessments are not carried out at inspector level. If accepted, the report results in the final Statement to the Government.

The standard NPT statement reports if nuclear material has been satisfactorily accounted for during the period between physical inventory takings. If the Agency is not satisfied with results obtained during inspections, further investigation is called for and the State is requested to examine the causes of any inadequacy and undertake the steps necessary to remedy the situation. (For non-NPT type Agreements the statement merely reports whether the IAEA has or has not detected deviations from the Agreement.)

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SESSION 8c: IAEA INTERNATIONAL SAFEGUARDS

IMPACT OF IAEA SAFEGUARDS ON STATE/FACILITY RECORDS AND REPORTS SYSTEM

C. G. Hough, IAEA

I. INTRODUCTION

The examination of records and reports of States and facilities is an important part of the inspection activities of the International Atomic Energy Agency (IAEA). The purpose of this report is to provide guidelines and recommendations that will enable States and facilities to design a records and reports system that will be responsible to the needs of IAEA Safeguards and enable inspectors to perform their duties in a timely fashion and with minimum interference to facility operations.

II. PURPOSES OF EXAMINATION OR RECORDS

The purposes of IAEA examination of records are:

1. To determine that an adequate State and facility system of accounting and control exists in principle, practice and as necessary under the applicable safeguards agreement.

2. To determine if the reports sent to the IAEA were accurate, complete and timely.

3. To assure that the facility has maintained a complete, correct and consistent statement of the status of declared nuclear material.

4. To determine a reliable book inventory by consolidation of the inventory change transactions that occurred between inspections for the purpose of verifying the shipments, receipts and other inventory changes.

5. To determine the composition (breakdown) of the inventory to the extent necessary to locate inventory changes or to verify the physical inventory taking (PIT) of the facility.

6. To determine the accuracy of the measurement methods used and their calibration and the measurement uncertainty of the material balance statement provided in the Material Balance Report (MBR).

7. To determine the likely causes of discrepancies found, material unaccounted for (MUF), Shipper-Receiver differences (SRD) and the potential magnitude of unmeasured losses and inventory holdup.

The records examination and related verification activities have four basic benefits to the Safeguards Program:

1. They have a deterrent effect on a potential diverter.

2. They can indicate the possibility of diversion of nuclear materials over a period of time.

3. They confirm, correct and enhance the States system of accounting and control (SSAC) of nuclear material subject to safeguards as deficiencies are exposed and corrected.

4. They can provide assurance of the effectiveness of the SSAC.

III. TERMINOLOGY

Accounting terminology varies widely in theory and practice and often leads to confusion and misunderstandings. Recognizing that it may be impossible to obtain complete agreement on terminology, the Agency has attempted to define many of the important terms used in international safeguards by publishing a Safeguards Glossary. Chapter V on Nuclear Material Accountancy and Chapter IX on Information, Records, Reports, Inspections are attached hereto for reference and study. Of particular interest is definition 110, Nuclear Material Accountancy, which shows the distinction between facility, State and IAEA activities; definition 114, IAEA Examination of Records; definition 115, IAEA Examination of Accounting Records; definition 145, Inventory Change (Flow) Verification; and definition 146, Inventory Verification.

In INFCIRC 153 the term "examination" is used to denote the activities connected with review, comparison and assessment of facility records and State reports relevant to safeguards, while in INFCIRC 66 the term "audit" is generally understood to cover the same activities. As a result the term "examine" and "audit" are often used interchangeably and should be accompanied by other adverbs in order to communicate the clear meaning, e.g., examination (audit) of operating records, assessment audit (examination), compliance audit (examination), quality audit (examination), etc.

IV. PROPOSED DEFINITIONS FOR NAMES OF RECORDS[1]

GENERAL LEDGER (sometimes called "inventory account"): Such a ledger contains continuously or periodically updated inventories of each category of nuclear material inside a material balance area (MBA). The book inventories are calculated with the help of inventory changes and adjusted after a physical inventory has been taken in the plant by an entry called "material unaccounted for" (MUF). Example under ANNEX 1.

CONTROL ACCOUNTS: In case the General Ledger is updated on a periodic basis with periodic sums of inventory changes, Control Accounts for each type of inventory change and each category of nuclear material are sometimes kept. Such Control Accounts contain daily figures and represent therefore the supporting records for updating the General Ledgers. Apart from quantities of nuclear material they contain references to shipping documents, analytical reports, batch numbers, packing lists, etc.

SUBSIDIARY LEDGERS: These ledgers contain the inventories of nuclear material in each accounting sub-area and the movements of nuclear material within the plant. The main feature of subsidiary ledgers is the breakdown of each category of nuclear material within the MBA, which represents the important list of nuclear material in case of a physical inventory verification.

SUPPORTING DOCUMENTS: Records which contain identity data, source data and batch data for each accounting transaction, such as shipping documents, weight (volume) records, laboratory reports, and change/discharge and irradiation records. These records form the basis for posting inventory changes in Control Accounts and in Subsidiary Ledgers.

V. RECOMMENDED RECORDS FOR DIFFERENT TYPES OF FACILITIES

Since each operator of a nuclear facility is keeping records of nuclear material in his facility for economic, health and safety reasons anyway, the question arises whether these records are adequate for IAEA safeguards. Experience has shown that except for a very few cases they are. It is obvious that the type of records an operator needs to keep depends on many factors, such as type and size of the facility, number of different categories of nuclear material in his facility, number of inventory changes during a certain time period, number of accounting sub-areas, etc.

The simplest records system in accordance with the IAEA requirements (a storage facility, for example), consists of a general ledger for each category of nuclear material together with the relevant supporting records. Such a records system is illustrated in Figure 1.

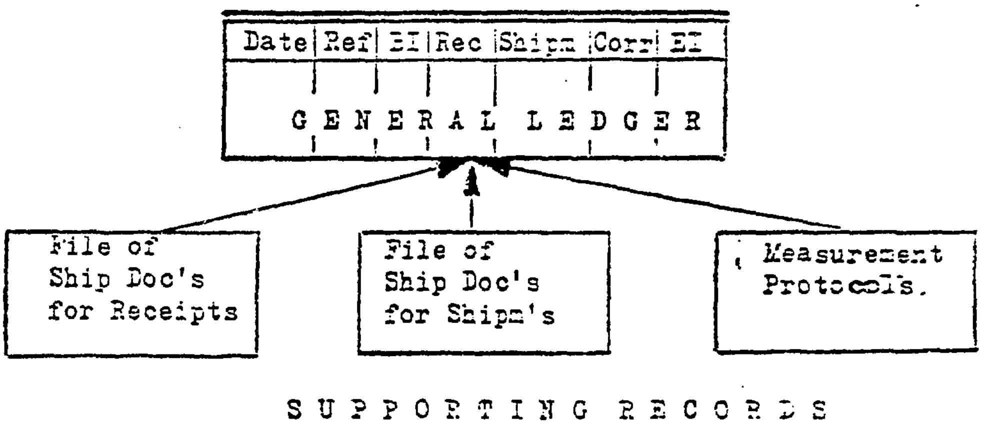

Fig. 1. Example of a records system for a simple storage facility.

For research reactors and nuclear power plants, the records system kept by plant operators differs from facility to facility. In most cases, especially for nuclear power plants, the general ledgers are replaced by computer printouts. Such computers are usually fed with the nuclear material content of fresh fuel received on the basis of the fuel fabricator's shipping documents as well as with reactor operating data. The computer then calculates the isotopic changes of the nuclear material inside the reactor core. In some plants the input of operating data to the computer is carried out on a continuous basis and therefore it is possible to have the nuclear material inventories of the plant at any time by a printout. In most cases however the operational calculation is made on a periodic basis (e.g., monthly), so that it is not possible to have a daily updated inventory. A possible records system for a nuclear power plant is illustrated in Figure 2.

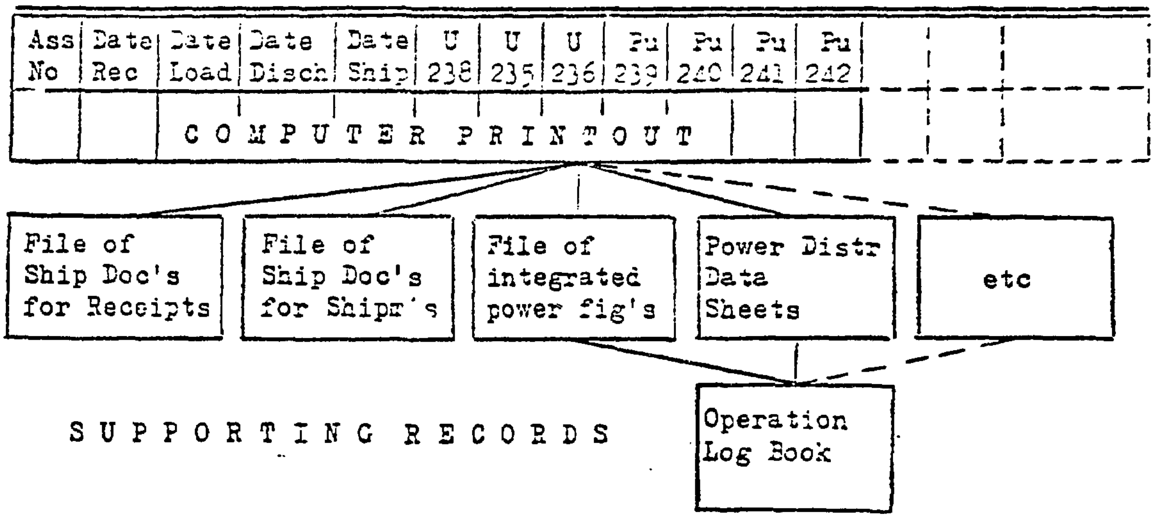

Fig. 2. Example of a records system for a nuclear power plant.

In case the number of fuel bundles in a nuclear power plant is relatively large (several hundred or more), the operator usually keeps a summarized inventory, established on the basis of the computer printouts. This reduces his workload when the reports to the IAEA have to be written. Such summarized fuel inventories would include the number of fuel bundles and their content of nuclear material for each accounting sub-area (for example, the cold fuel store, the reactor core, and the irradiated fuel store). Some other operators keep, for each fuel bundle, a card in which the fuel bundle history is described. This information may include date of receipt, data of loading to the core, dates of reshuffling in the core, date of discharge from the core, date of shipment, corresponding material quantities and burnup. Each reactor operator keeps tag boards on which the configurations of fuel elements or bundles are indicated for the core and usually also for the irradiated fuel pond. These tag boards represent accounting records, which can be crosschecked with the computer printouts or the summarized inventories. All records containing data on reactor operation as well as data on internal fuel movements (fuel change orders, SS material transfer forms, etc.) are to be classified as operating records.

In bulk material facilities, such as fuel fabrication plants, conversion plants, enrichment plants or fuel reprocessing plants, the nuclear materials are present in many different chemical and physical forms. Such plants are usually subdivided into a number of different accounting sub-areas making uniform accounting of nuclear material more complicated. It is therefore necessary for the operator of such a plant to keep a records system with a minimum of redundancy but with a maximum of efficiency in order to know the quantity of nuclear material at any location of his plant in the shortest time possible. Such a records system must include a general ledger for each category of nuclear material and for the whole MBA, control accounts for each group of inventory changes and subsidiary ledgers for each accounting sub-area. Only then is it possible for both the plant operator and the IAEA inspectors to assess any part of a certain category of nuclear material quantitatively and by location in a straightforward way. An example of a records system for a relatively small sized chemical reprocessing plant is illustrated in Figure 3.

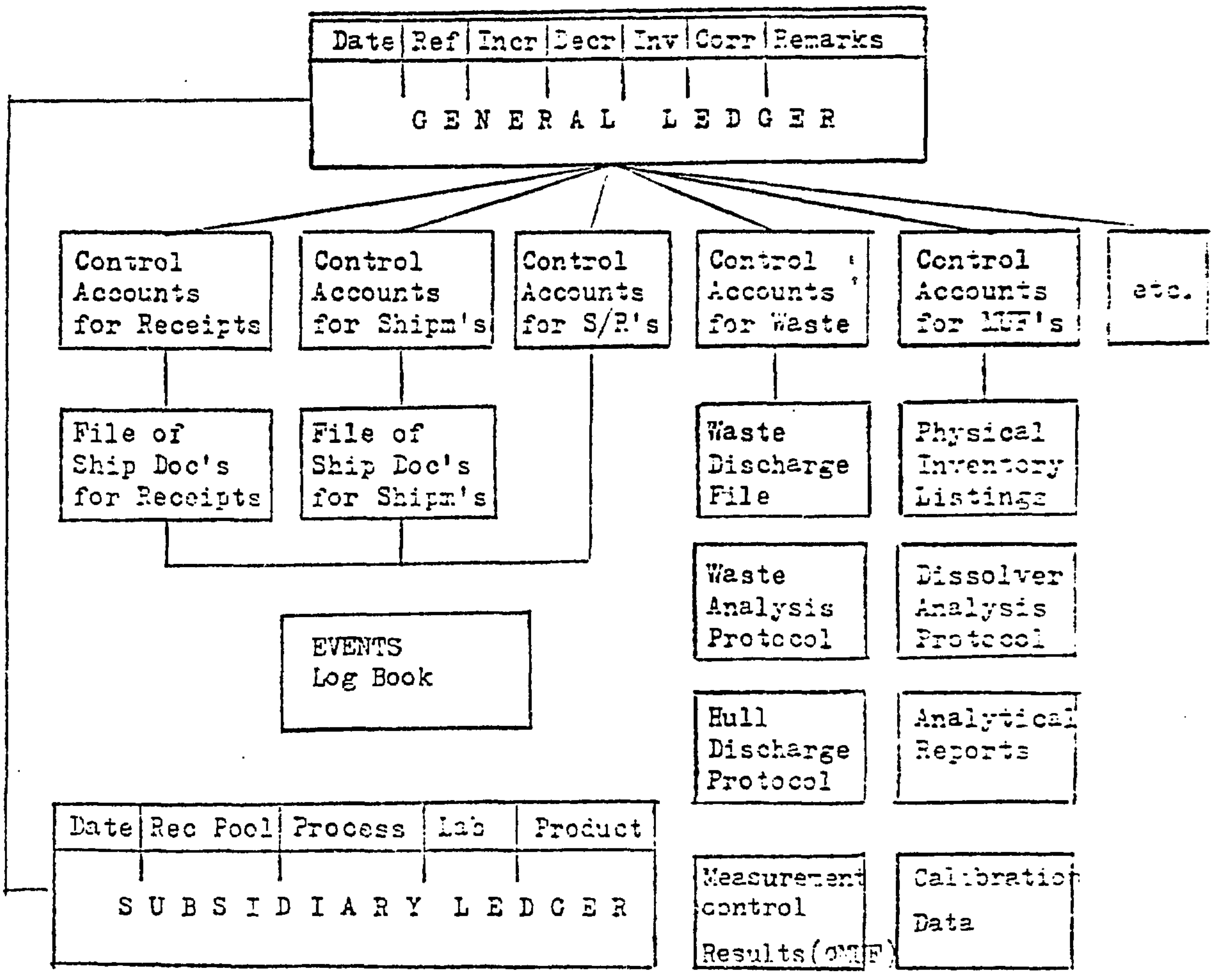

Fig. 3. Example of a records system for a small chemical reprocessing plant.

VI. UNIFIED URANIUM ACCOUNTANCY

In many facilities handling uranium enriched to less than 20 percent U235, separate accounts are maintained for depleted, natural and low enriched uranium. This often means the inspector must combine together several accounts in order to establish the book inventory for uranium. This is especially troublesome for power reactors where safeguards are based primarily on item counting and identification of fuel assemblies. Maintaining separate books for the enrichment category changes, from slightly enriched to depleted due to the irradiation process, is not important. Considerable time and effort could be saved by the operator and inspector if unified uranium accounting were applied to uranium enriched to less than 20 percent U235. Thus, only one ledger account would be needed in place of three separate accounts. If the initial enrichment is greater than 0.712 percent U235 then both element and isotope weight would be recorded and reported, otherwise, only element weight would be required.

VII. BATCH DATA, SOURCE DATA AND OPERATING DATA

Some examples of these data are listed below:

Batch Data. Number of items/batches (N), Element Weight (EW), and Isotope Weight (IW).

Source Data. Gross Weight (G), Tare Weight (T), Net Weight (N), Volume (V), Liquid Level (L), Density (D), Element Concentration (Uranium) (E), Isotope Ratios, and Conversion Factors and derived relationships such as between plutonium produced and power generated.

Operating Data. Integrated power level, MWD/tU, discharge date, etc.; Calibration data for tanks, instruments and scales; Measurement and sampling methods, dates and number of samples taken and measurements made; Procedures to control quality of measurements; Estimates of random and systematic errors of measurements, error propagation procedures; Procedures for clean out and taking of physical inventory; Recording of actions and events that would enable determination of cause and magnitude of an accidental loss or an unmeasured loss that might occur or unmeasured inventory holdup.

Batch data and source data are recorded in accounting records and operating data are recorded in operating records. However, the borderline between accounting and operating records is not always clear and may vary depending on facility practice and the safeguards agreement. The distinction is not very important as long as each record has a name and is easily accessed by the inspector.

Source data are combined arithmetically to obtain batch data; for example, the isotope weight for U-235 in a single item might be:

$$IW = (G-T)\ CE = WCE.$$

Also, the isotope weight in a batch or control account would be obtained by adding up each item to obtain a total.

$$\text{Total U-235} = \sum_N IW = \sum_N WCE$$

During the examination of accounting records the inspector will check to see if these calculations are arithmetically correct by repeating the calculations using the source data, usually on a statistical sampling basis. He would record any discrepancies found and determine if explanations and corrective actions are necessary. The objective is to detect and eliminate discrepancies or mistakes in recording that are very large compared to normal measurement errors and which would have a serious effect on the material balance statement. The facility can also perform this kind of check as part of an internal audit program.

Batch data are reported to the IAEA in accounting reports. Source data and operating data are recorded at the facility but not reported to the IAEA. The inspector extracts the source data and operating data from facility records in the form of working papers or uses computer printouts provided by the operator. The inspector also records the results of verification measurements in working papers and evaluates the results by comparison to the operator's source and batch data. This transcription of data into working papers can result in recording errors. In the case of reprocessing plants, the date for decay correction of plutonium can be a problem depending on whether the comparison date is the date of discharge from the reactor, the beginning date of the campaign or the date the reprocessed plutonium is shipped to a fabrication plant. This also affects the SRD and MUF for the plant.

As a result of these common difficulties it is necessary to clearly specify the recording, reporting and comparison basis for batch and source data. Improved methods are also needed for the transcription of important source data onto inspection working papers in order to minimize recording errors. The Agency and some States[2] are cooperating to this end to use minicomputers to transfer source data on magnetic tape or hard copy printouts and inspectors are starting to use small, portable minicomputers in the field for this purpose.[3]

Periodically, the ispector will carry out an "examination of operating records" and this usually parallels the "examination of accounting records." The practice varies considerably depending on the type of facility, the type of operating data and the completeness of the operating records. In the case of power reactors, the examination of operating records is primarily aimed at confirming nuclear loss and production and confirming that the reactor was operated at the declared power levels since the last inspection. For bulk handling facilities, emphasis is placed on examination of operating data for sampling and analysis, the accuracy of measurements and the frequency and accuracy of the calibration of scales, tanks and instruments. Procedures for cleanout of facilities and estimating holdup of inprocess materials at the time of the PIT are also of high interest. Of particular value is the maintaining of a record of events that occur during operation that may have an impact on the material balance. Such a record is very useful at a later date when the material balance is closed and explanations for MUF and discrepancies in operator/inspector comparisons are needed.

VIII. ACCOUNTING REPORTS

The various types of accounting reports are defined in the attached glossary. They are quite well known and will not be discussed here. Procedures for reporting to the IAEA[4] are explicitly defined in the Subsidiary Arrangements to each Safeguards Agreement. Each year the Agency holds a Safeguards Workshop Seminar that is especially designed for Reports Officers in States; the workshop has been very successful in improving the accuracy and timliness of accounting reports. All Reports Officers are encouraged to attend this annual workshop (6-10 October 1980).

IX. COMPARISON OF ACCOUNTING REPORTS AND RECORDS

This is one of the main activities of the IAEA examination of records. The Inventory Change Reports (ICR) and the corresponding book inventory are compared to the General Ledger and Control Accounts to see if they are in agreement. If not, explanations and corrective actions are taken to bring the facility records, State Reports and Agency records into line with one another. This comparison may be carried out in one of two ways.

In the first procedure, the inspector carries out an examination of the records for an examination period where the facility records have been closed and reports dispatched to the State level. The inspector records the consolidated summary of inventory changes and the book inventory for the end date of the examination period in working papers. Later at Headquarters after the ICR has been received from the State a comparison is made to the working paper data.

In the second procedure, the comparison is delayed until the ICR is received at Headquarters and a printout provided to the inspector from the Agency computer. The inspector takes the printout to the facility on the next inspection for a direct comparison to the General Ledger and Control Accounts.

There are advantages and disadvantages to both procedures. The first procedure is more timely and provides a greater deterrent to falsification of data. However, it requires more effort by the inspector and the resulting comparison may not be accurate due to corrections made before the ICR was dispatched to the IAEA. The second procedure provides a lesser deterrent to falsification and places the main burden of independent verification on item counting and identification and measurements by the inspector. However, it is easier for the inspector to carry out and it may be more accurate and result in fewer discrepancies that require explanation and corrective action.

X. STRATIFICATION OF INVENTORY

The various components of a material balance are established by the facility operator on the basis of measurements. These same data are used by IAEA inspectors for verification purposes. Measurement procedures and the formulation of sampling plans can be simplified considerably if the various items and batches with similar characteristics are grouped into strata. Such groupings are also advantageous to facility operators for the purpose of determining the number of measurements needed to establish the material balance and compute its uncertainty (σ_{MUF}).[6,7]

The listing of a facility's inventory of record (book inventory composition) will normally be by groups that are logical from the standpoint of taking the physical inventory. The groups, or strata, may be organized by material location and subgrouped by the type of material which are assumed to have the same measurement basis. A listing by location will be useful to inspectors for item counting to verify that all items are present and the book inventory is complete and also for selection of items for sampling and measurement.

Grouping by the type of material even though the same material may reside in two or more locations is useful for preparing sample plans for the verification of the inventory.[8] The consistent use of a material description system or code is advisable to make this type of stratification easy to carry out on a computer.[9] Of related importance is identification of the measurement techniques or equipment used to determine the nuclear material content of each type of bulk material. This is necessary in order for the operator to be able to maintain a measurement control program for bulk materials that require measurement, to estimate measurement errors and to calculate the uncertainty in the physical inventory taking.

An example of the stratification of the inventory at a uranium fabrication facility according to material type and location is demonstrated in Table 1. The desired summary information for each material type/location intersection is the number of items/batches, the total element weight and total isotope weight (if relevant). These same quantities can be summed together in the bottom row to obtain the totals for each location or in the last column to obtain the totals for each material type. This is easy to accomplish on a computer if a reliable material description code, location code and measurement basis code can be defined for each item/batch. An example of such a computation is given in Table 2. Table 3 is an example of the list of items to be found at one location organized by material type and giving the total amounts for each material type at that location.

This recommended system of stratification is very important for large facilities involving thousands of items. Without it, the inspector will have a very difficult time to examine and stratify the list of materials, to carry out the inventory verifications, to evaluate the results and to prepare a statement on the conclusion of the inventory verification.[9] For small facilities and many light water reactors the situation is easier since the locations and material types are fewer in number.

Table 4 is an example of the data needed for each spent fuel assembly at a reactor or reprocessing plant. In most cases this information is available in the form of a computerized list and represents one stratum at a power reactor.

TABLE 1

Example of Stratification by Material Type and Location

Location / Material Type	1 Receiving Pad	2 Shop Support Area	3 Stacker Warehouse	4 Mezzanine Warehouse	5 Rod Load Area	6 Nuclear Poison Shop	7 Bundle Assembly Room	8 Shipping Area	9 Laboratory Storage	Material Type Totals
A. UF_6 Cylinder	▲	▲								
B. UO_2 Pellets					▲	▲				
C. Bundles							▲	▲		
D. Fuel Rods						▲	▲			
E. UO_2 Powders			▲	▲		▲				
F. U_3O_8 Powder		▲								
G. Solid Waste and Sludge										
H. Clean Scrap			▲							
J. Scrap Residue, Sludge		▲				▲				
K. Laboratory Samples									▲	
L. In Process, Misc.		▲				▲	▲	▲		
LOCATION TOTALS →										

▲ Indicates the amount of material and number of items

Table 2 KMP-MTL-LOCATION SUBTOTALS

KMP	MTL		MDA TOTAL	LOC10	LOC15	LOC20	LOC25	LOC30	LOC35	LOC40	LOC45	LOC50
A	RD	N	32.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	32.000	0.000
		SUMU	1637.376	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1637.376	0.000
		SUMUS	22.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.059	0.000
F	DS	N	15.000	0.000	0.000	0.000	0.000	0.000	15.000	0.000	0.000	0.000
		SUMU	453.041	0.000	0.000	0.000	0.000	0.000	453.041	0.000	0.000	0.000
		SUMUS	7.499	0.000	0.000	0.000	0.000	0.000	7.499	0.000	0.000	0.000
G	VS	N	6.000	0.000	0.000	0.000	0.000	0.000	6.000	0.000	0.000	0.000
		SUMU	67.869	0.000	0.000	0.000	0.000	0.000	67.869	0.000	0.000	0.000
		SUMUS	1.425	0.000	0.000	0.000	0.000	0.000	1.423	0.000	0.000	0.000
K	US	N	5.000	0.000	5.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMU	48.100	0.000	48.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMUS	0.871	0.000	0.871	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M	AS	N	10.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	10.000
		SUMU	1785.283	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1785.283
		SUMUS	49.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	49.095
P	P1	N	5.000	0.000	0.000	5.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMU	3774.952	0.000	0.000	3774.952	0.000	0.000	0.000	0.000	0.000	0.000
		SUMUS	58.753	0.000	0.000	58.753	0.000	0.000	0.000	0.000	0.000	0.000
R	P1	N	8.000	0.000	0.000	6.000	1.000	1.000	0.000	0.000	0.000	0.000
		SUMU	392.178	0.000	0.000	330.870	47.606	15.004	0.000	0.000	0.000	0.000
		SUMUS	2.645	0.000	0.000	2.197	0.413	0.035	0.000	0.000	0.000	0.000
	P3	N	12.000	0.000	0.000	10.000	1.000	1.000	0.000	0.000	0.000	0.000
		SUMU	321.130	0.000	0.000	273.090	47.534	50.507	0.000	0.000	0.000	0.000
		SUMUS	3.794	0.000	0.000	3.232	0.461	0.101	0.000	0.000	0.000	0.000
T	UH	N	3.000	0.000	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMU	460.000	0.000	460.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMUS	8.254	0.000	8.254	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	GD	N	2.000	0.000	0.000	0.000	0.000	0.000	0.000	2.000	0.000	0.000
		SUMU	62.447	0.000	0.000	0.000	0.000	0.000	0.000	62.447	0.000	0.000
		SUMUS	1.474	0.000	0.000	0.000	0.000	0.000	0.000	1.474	0.000	0.000
	PL	N	8.000	0.000	0.000	0.000	0.000	0.000	8.000	0.000	0.000	0.000
		SUMU	131.619	0.000	0.000	0.000	0.000	0.000	131.619	0.000	0.000	0.000
		SUMUS	1.717	0.000	0.000	0.000	0.000	0.000	1.717	0.000	0.000	0.000
W	UF	N	20.000	15.000	5.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMU	21750.514	16576.003	5174.509	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		SUMUS	321.704	241.620	80.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LOC TOTAL		N	126.000	15.000	13.000	21.000	2.000	2.000	29.000	2.000	32.000	10.000
		SUMU	30961.539	16576.005	5691.609	4190.920	95.140	66.300	653.429	62.447	1637.376	1785.283
		SUMUS	480.110	241.620	99.201	64.182	0.874	0.136	10.661	1.474	22.058	49.095

Table 5

SEQ. NO.	ITEM NO.	LOC CODE	KMP CODE	MATERIAL TYPE	MAT CODE	CONTAINER TYPE	MEAS DATE	SCALE NO.	GROSS WEIGHT	TARE WEIGHT	NET WEIGHT	PERCENT URANIUM	URANIUM WEIGHT	PERCENT U-235	U-235 WEIGHT
73	DG22	35	F	DRY SCRAP UO2	DS	DRUMS	770715	S1	8.076	1.346	6.730	87.000	5.855	2.500	0.146
[illegible]	DG8A	35	F	DRY SCRAP UO2	DS	DRUMS	770714	S1	23.808	3.968	19.840	87.200	17.300	2.130	0.369
[illegible]	DG35	35	F	DRY SCRAP UO2	DS	DRUMS	770713	S1	45.180	7.530	37.650	86.520	32.575	2.020	0.658
[illegible]	DG40	35	F	DRY SCRAP UO2 &	DS	DRUMS	770712	S1	17.040	2.840	14.200	83.910	11.915	1.850	0.220
[illegible]	DG913	35	F	DRY SCRAP UO2	DS	DRUMS	770711	S1	15.984	2.664	13.320	87.200	11.615	1.750	0.203
[illegible]	DG912	35	F	DRY SCRAP UO2	DS	DRUMS	770710	S1	67.344	11.224	56.120	87.200	48.937	1.750	0.056
[illegible]	DG06	35	F	DRY SCRAP UO2	DS	DRUMS	770709	S1	33.049	5.509	27.540	87.200	24.015	1.200	0.307
[illegible]	DG05	35	F	DRY SCRAP UO2	DS	DRUMS	770708	S1	37.656	6.276	31.380	87.200	27.363	1.200	0.350
[illegible]	DG93	35	F	DRY SCRAP POWDER	DS	DRUMS	770707	S7	0.539	0.090	0.448	87.400	0.392	1.750	0.007
[illegible]	DG58	35	F	DRY SCRAP	DS	DRUMS	770706	S7	278.620	46.430	232.190	84.000	195.040	1.750	3.413
[illegible]	DG73	35	F	DRY SCRAP AUC	DS	DRUMS	770705	S1	5.016	0.836	4.180	86.500	3.616	1.400	0.051
[illegible]	DG47	35	F	DRY SCRAP UO2 &	DS	DRUMS	770704	S1	23.448	3.908	19.540	80.700	15.769	1.400	0.221
[illegible]	DG90	35	F	DRY SCRAP	DS	DRUMS	770703	S5	45.329	7.555	37.774	84.000	31.730	1.180	0.374
[illegible]	DG59	35	F	DRY SCRAP UO2 A	DS	DRUMS	770702	S1	5.556	0.926	4.630	87.400	4.047	1.160	0.047
[illegible]	DG59	35	F	DRY SCRAP UO2	DS	DRUMS	770701	S1	32.640	5.440	27.200	87.400	23.773	1.160	0.276
											532.742		453.941		7.499
[illegible]	PGA87	35	V	UO2 SINTERED PEL	PL	TRAYS	770708	S7	42.437	7.073	35.364	88.100	31.156	1.750	0.545
[illegible]	PG307	35	V	UO2 SINTERED PEL	PL	TRAYS	770707	S5	21.781	3.630	18.151	88.100	15.991	1.280	0.205
[illegible]	PG39A	35	V	UO2 SINTERED PEL	PL	TRAYS	770706	S1	26.406	4.401	22.005	88.100	19.396	1.280	0.248
[illegible]	PG01A	35	V	UO2 SINTERED PEL	PL	TRAYS	770701	S3	19.156	3.193	15.963	88.100	14.063	0.970	0.136
[illegible]	PG599	35	V	UO2 SINTERED PEL	PL	TRAYS	770705	S6	3.475	0.579	2.896	88.100	2.551	1.180	0.030
[illegible]	PG306	35	V	UO2 SINTERED PEL	PL	TRAYS	770704	S6	35.166	5.861	29.305	88.100	25.818	1.180	0.305
[illegible]	PG039	35	V	UO2 SINTERED PEL	PL	TRAYS	770703	S6	3.532	0.589	2.943	88.100	2.593	1.180	0.031
[illegible]	PGA8A	35	V	UO2 SINTERED PEL	PL	TRAYS	770702	S5	27.324	4.554	22.770	88.100	20.060	1.180	0.237
											149.397		131.619		1.737
[illegible]	WG036	35	G	WET SCRAP	WS	DRUMS	770704	S1	100.740	16.790	83.950	8.950	7.514	2.100	0.158
[illegible]	WG35	35	G	WET SCRAP	WS	DRUMS	770703	S1	103.500	17.250	86.250	17.380	14.990	2.100	0.315
72	WG014	35	G	WET SCRAP	WS	DRUMS	770702	S1	99.360	16.560	82.800	18.390	15.227	2.100	0.320
[illegible]	WG033	35	G	WET SCRAP	WS	DRUMS	770701	S1	82.140	13.690	68.450	25.710	17.598	2.100	0.370
[illegible]	WG035	35	G	WET SCRAP	WS	DRUMS	770706	S1	87.540	14.590	72.950	10.740	7.835	2.100	0.165
75	WG025	35	G	WET SCRAP	WS	DRUMS	770705	S1	79.090	13.180	65.900	7.140	4.705	2.100	0.099
											460.300		67.869		1.425
											1142.439		653.429		10.661

TABLE 4 ASSEMBLY DATA OF THE FUEL TO BE REPROCESSED AT ____________ DURING CAMPAIGN NO. ____

ASSEMBLY		INITIAL DATA			CHARGING DATE	DIS-CHARGING DATE	VOID FACTOR (AVE)	FINAL DATA (ESTIMATED)											
ID	NO.	TOTAL U WT (KGS)	U-235 ENRICH	U-235 WT %				EXPOSURE MWD/TU	U-234	U-235	U-236	U-238	TOTAL U WT (KGS)	PU-238	PU-239	PU-240	PU-241	PU-242	TOTAL PU WT (GMS)
									UNIT: WT%, GMS, OR					UNIT: WT%, GMS, OR					
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

XI. STRATIFICATION OF INVENTORY CHANGES

Stratification of inventory changes is usually easier because each transaction is characterized in an Inventory Change Report (ICR) according to Key Measurement Point (KMP) Code, Type of Inventory Change, Material Description Code, Partner MBA and, if they are recorded, in separate Control Accounts. This information is explicitly defined in Subsidiary Arrangements for each MBA and KMP.

From the records examination and for each major type of transaction, the inspector needs to know the total number of items/batches, the total element weight and total isotope weight (if relevant). This is most easily obtained from control accounts, especially if cumulative or running totals are maintained in each control account since the last PIT. Thus, if the inspector needs the totals between two inspection dates for any given material, he can calculate them as the difference between the cumulative totals that correspond to those dates. In addition, the inspector needs to know the location where the inventory changes can be found if they are still available in an identifiable form or are being prepared for shipment to another facility. Finally, the inspector needs to know the book inventory on the date of the inspection as the basis for the verification of inventory changes. These inventory changes can be traced to State Reports and records at a later date.

In the case of intermittent inspections this is very difficult to achieve for large facilities that handle many transactions because all transactions may not be entered on the control accounts as of the date of inspection, the location status may not be up-to-date and it may be difficult for the inspector to identify which items were received since the last inspection. In this situation, a computerized summary of the inventory changes as close to the date of inspection as possible is needed before a meaningful flow verification can be carried out. Also, some kind of sealing or item identification system is urgently needed so that the identification of the transactions can be quickly determined.

In the case of continuous inspection the situation is less difficult but can still be a burden to the inspector if the number of transactions are large and computerized summaries are not available.

Inventory change verification is a very important part of IAEA Safeguards when the throughput of a facility is large and physical inventory taking is infrequent. This is true because the amount of material and the measurement uncertainty associated with inventory changes represent a large part of the uncertainty in the material balance reported by the State in an MBR. Obviously, without verification of the increases, decreases and ending physical inventory, evaluation of MUF using the material balance concept is not possible and the Agency is unable to make a technical conclusion statement.

However, flow verification can be enhanced by consideration of the primary flow KMPs in the State and taking advantage of the confirmation provided by international transfers, timely reporting and evaluation of Shipper-Receiver Differences and

Transit Accounts between MBAs, by coordination of inspection between MBAs and other technical crosschecks that take advantage of the capabilities of each fuel cycle, fuel specifications, reactor calculations and isotope correlations.[10,11]

XII. MEASUREMENT CONTROL PROGRAM

The State should ensure that guidelines are established for the design and implementation of a measurement control programme at those facilities where accountability measurements are important. The purpose of such a programme is to determine the accuracy of measurements and the credibility of facility material balance statements.

At the present time, very few States have implemented such guidelines and very few operators maintain records or provide measurement accuracy data in design information. As a result, in the majority of cases, it has not been possible to establish limits of accuracy for MUF and shipper-receiver differences and to evaluate the statistical significance of these indicators. The purpose of this paper is to provide information to States that will enable setting up of measurement control programmes that are adequate for safeguards, accountancy and control, and reduction of costs due to losses of nuclear material.

The measurement control programme should:

a) Make use of certified standards and other standard materials for calibration and also provide a basis for establishing systematic errors in measurements including nondestructive assay.

b) Provide the basis for the estimation of measurement uncertainty, including evaluation of the random and systematic errors associated with weight, volume, sampling and analytical measurements, and nondestructive assay measurements.

c) Provide statistical methods for processing measurement and calibration data, to combine (propagate) uncertainties associated with S/R differences, inventory changes, physical inventory, and MUF.

d) Provide for bias adjustments to accountancy data.

e) Establish limits of uncertainty and bias for each key measurement point, for inventory changes, physical inventory, book inventory and MUF, in conjunction with criteria for the facility as defined by the State.

Statistical methods for estimation of measurement errors and propagation of those errors to obtain σ_{MUF} are given in Part F, Volume 1 of the Safeguards Technical Manual.[13] Reference 15 describes a useful computer program (NUMSAS) for computing σ_{MUF} that uses information from the DIQ, ICR, and PIL. It can be acquired on magnetic tape at a very low cost by writing to:

EURATOM PROGRAM DISTRIBUTION AGENCY (EPDA)
EUROCOPI - DEPT. A, J.R.C. EURATOM
I - 21020 ISPRA, ITALY.

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APPENDIX I

SAFEGUARDS GLOSSARY, CHAPTER V.

NUCLEAR MATERIAL ACCOUNTANCY

Nuclear material accountancy within the framework of IAEA safeguards begins with the nuclear material accounting activities which are undertaken by or on behalf of facility operators in response to requirements set by the State's System of Accounting for and Control of Nuclear Material (SSAC), arising from obligations defined in agreements between the IAEA and the State. These activities and the corresponding accounting information generated are verified through independent IAEA inspection. These inspection activities, after evaluation, provide one of the means of detecting diversion and of deterring diversion by the risk of early detection. They also make it possible to determine the degree of assurance provided by the safeguards measures. Other important chapters in this Glossary bearing on nuclear material accountancy are:

Chapter VI Physical Standards, Sampling, Measurement

Chapter VII Statistical Concepts

Chapter IX Information, Records, Reports, Inspections.

109. Nuclear Material Accounting - the activities carried out to establish the quantities of nuclear material present within defined environments and the changes in those quantities taking place within defined periods of time. Essential elements of nuclear material accounting are material measurements, record keeping, preparation and submission of accounting reports,

verification and analysis of these accounting data to determine correctness, accuracy of MUF and evaluation of causes of MUF.

110. Nuclear Material Accountancy - The practice of nuclear material accounting by the facility operator and the SSAC and, in addition, the verification and evaluation of this accounting system by a safeguards authority (SSAC or IAEA) with subsequent statements of results and conclusions which make it possible to determine the degree of assurance provided by the safeguards measures. Accountancy includes activities such as:

Facility Level

- dividing nuclear material operations into material balance areas (MBA);
- maintaining records describing the quantities of nuclear material held within each MBA;
- measuring and recording all transactions involving the transfer of nuclear material (international or domestic) from one MBA to another or changes in the amount of nuclear material present due to nuclear production or nuclear loss;
- periodically determining the quantities of nuclear material present within each MBA through the taking of the physical inventory;
- closing the material balance over the time period spanned by two successive physical inventories and computing the material-unaccounted-for (MUF) for that period;

- providing for a measurement control programme to determine accuracy of measurements and calibrations and correctness of recorded source and batch data;
- testing the computed MUF against its limits of error for indications of undetected loss;
- analyzing the accounting data to determine the cause and magnitude of mistakes in recording, unmeasured losses, accidental losses and unmeasured inventory (holdup);

SSAC Level

- preparing and submitting accounting reports to the IAEA as appropriate;
- ensuring that the accounting procedures and arrangements are correctly adhered to;
- providing for inspector access and coordination arrangements as necessary to enable the IAEA to carry out its verification activities;
- providing for independent verification by the SSAC of facility operators' safeguards performance, as appropriate.

IAEA Level

- independently verifying nuclear material quantities and locations, using inspection methods such as: examination of accountancy records and comparison with accounting reports, item counting and identification, independent measurements, verifying the operation and calibration of instruments and other measurement and control equipment, verifying information on possible causes of MUF, of shipper/receiver differences and uncertainties in the book inventory, and carrying out other activities as provided for in the safeguards agreement;

- determining the effectiveness of the SSAC;
- providing statements on the IAEA verification activities to the State; and
- providing statements for the annual SIR for the Board of Governors on the effectiveness of IAEA safeguards.

111. Material Balance Area - "an area in or outside of a facility such that:

(a) The quantity of nuclear material in each transfer into or out of each 'material balance area' can be determined; and

(b) The physical inventory of nuclear material in each 'material balance area' can be determined when necessary, in accordance with specified procedures,

in order that the material balance for Agency safeguards purposes can be established" [153/para. 110].

Design information made available to the Agency shall be used: "To determine material balance areas to be used for Agency accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories; in determining such material balance areas the Agency shall, inter alia, use the following criteria:

(i) The size of the material balance area should be related to the accuracy with which the material balance can be established;

(ii) In determining the material balance area advantage should be taken of any opportunity to use containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;

(iii) A number of material balance areas in use at a facility or at distinct sites may be combined in one material balance area to be used for Agency accounting purposes when the Agency determines that this is consistent with its verification requirements; and

(iv) If the State so requests, a special material balance area around a process step involving commercially sensitive information may be established" [153/para. 46(b)].

112. Strategic Point - "a location selected during examination of design information where, under normal conditions and when combined with the information from all 'strategic points' taken together, the information necessary and sufficient for the implementation of safeguards measures is obtained and verified; a 'strategic point' may include any location where key measurements related to material balance accountancy are made and where containment and surveillance measures are executed" [153/para. 116].

113. Key Measurement Point - "a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. 'Key measurement points' thus include, but are not limited to, the inputs and outputs (including measured discards) and storages in material balance areas" [153/para. 108].

114. IAEA Examination of Records - An independent review, comparison and assessment of facility records and State reports, with an intent to report and, to the extent relevant, verify material quantities stated in such records and reports. Records examination consists of all or part of the following activities:

- examining accounting records;
- comparing facility records with State reports and/or notifications;
- updating the book inventory, including a summary of inventory changes for verification purposes;
- summary of the composition of inventory for material verification purposes; and
- examining operating records.

In [153] the term "examination" is used to denote these activities connected with review, comparison and assessment of facility records and State reports relevant to safeguards, while in [66] the term "audit" is generally understood to cover the same activities.

115. IAEA Examination of Accounting Records - An independent review, comparison and assessment of identity data, batch data and source data for a material balance area, with an

intent to report results and conclusions and, to the extent relevant, verify the information in the records; it includes:

- checking of supporting documents for arithmetical correctness and consistency whenever they are interrelated;
- checking that the data from the supporting documents are correctly reflected (transcribed) in the account records (ledgers);
- checking that the totals in the account records are arithmetically correct;
- recording the book inventory totals; and
- recording the physical inventory totals in the case of physical inventory taking (PIT).

116. Examination Period - The time between any two closing dates for which final data are recorded and in respect of which a State report is or will be prepared. The period may be divided into several sub-periods for the sake of convenience.

117. Closing Date - The date at which a report is or will be prepared or, in case no report is prepared, any date mutually agreeable to operator and inspector.

118. Inventory Change Summary Period. - The time period between inspections for which all inventory changes which have taken place are finally or provisionally documented, and can therefore be taken account of for the purpose of verifying the inventory change quantities/items stated in the records. The ending date of such period is the latest date for which all relevant data related to inventory changes are available to the

inspector; such date is also the beginning date for the subsequent inventory change summary period. It is essential that the beginning and ending dates of each material balance period should coincide with a beginning/ending date of an inventory change summary period.

119. Material Balance Period (MBP) - The time between two consecutive PITs as reflected in the State's material balance report (MBR) [153], or the time between two consecutive book inventory closing dates [66].

Note: In [66] agreements the terms material balance period and material balance report are used to refer to what more accurately should be called book balance period and material status report respectively, since there is no necessary link between them and PITs.

120. Examination Period for Operating Records - The time period between inspections for which all entries in a particular type of record have been fully or provisionally made, and can therefore be taken account of for the purpose of a records examination. The ending date of such period is the latest date for which all relevant data for each type of record are available to the inspector; such date is also the beginning date for the subsequent examination period for operating records. It is essential that the beginning and ending dates of each MBP should coincide with the beginning/ending date of an examination period for operating records.

121. Operating Records - "In respect of each material balance area:

(a) Those operating data which are used to establish changes in the quantities and composition of nuclear material;

(b) The data obtained from the calibration of tanks and instruments and from sampling and analyses, the procedures to control the quality of measurements and the derived estimates of random and systematic error;

(c) The description of the sequence of the actions taken in preparing for, and in taking, a physical inventory, in order to ensure that it is correct and complete; and

(d) The description of the actions taken in order to ascertain the cause and magnitude of any accidental or unmeasured loss that might occur" [153/para. 58].

122. Arithmetical Correctness - Absence of arithmetical errors, in particular:

- the absence of errors of addition, subtraction, multiplication and division, and in recording the determination of batch results from source data;
- the absence of errors in the summation and recording of item quantities to obtain batch, stratum, and account totals;
- the absence of errors in the identity data that characterize a particular batch, stratum or transaction.

123. Consistency - Freedom from contradiction among contents of related supporting documents.

124. Supporting Documents - Records which contain identity data, source data and batch data for each accounting transaction, such as shipping documents, weight (volume) records, laboratory reports, charge/discharge and irradiation records.

125. Batch Data - "The total weight of each element of nuclear material and, in the case of plutonium and uranium, the isotopic composition when appropriate. The units of account shall be as follows:

(a) Grams of contained plutonium;

(b) Grams of total uranium and grams of contained uranium-235 plus uranium-233 for uranium enriched in these isotopes; and

(c) Kilograms of contained thorium, natural uranium or depleted uranium.

For reporting purposes the weights of individual items in the batch shall be added together before rounding to the nearest unit" [153/para. 101].

126. Batch - "A portion of nuclear material handled as a unit for accounting purposes at a key measurement point and for which the composition and quantity are defined by a single set of specifications or measurements. The nuclear material may be in bulk form or contained in a number of separate items" [153/para. 100]. Some examples are:

- one fuel assembly
- one UF_6 cylinder
- a tray of pellets prepared for loading into one fuel rod
- several drums of UO_2 powder with the same specifications.

Items with the "same specifications" are items with the same nominal weight, element factor, and enrichment. There are cases where this is not necessarily true, e.g., scrap material which will be recovered together.

127. Source Data - "Those data, recorded during measurement or calibration or used to derive empirical relationships, which identify nuclear material and provide batch data. 'Source data' may include, for example, weight of compounds, conversion factors to determine weight of element, specific gravity, element concentration, isotopic ratios, between plutonium produced and power generated" [153/para. 115].

128. Identity Data - Those data needed to uniquely characterize an item, batch, stratum, or component, for example, serial number, MBA code, element code, material description code and type and date of inventory change.

129. Inventory Change - "An increase or decrease, in terms of batches, of nuclear material in a material balance area" [153/para. 107]; such a change shall involve one of the following:

(a) Increases: import, domestic receipt, nuclear production and de-exemption.

(b) Decreases: export, domestic shipment, nuclear loss, measured discard, retained waste, exemption, and other loss.

The above definition applies to NPT. Under [66], an inventory change is any receipt, transfer out, or use of all safeguarded nuclear material [66/para. 39(a)].

130. Account - A record of debit and credit entries chronologically posted to a ledger to cover transactions involving a particular type of stratum of nuclear material.

131. Account Total - The summation of the element (isotope) weight and/or the number of items in a particular type of stratum of nuclear material.

132. Account Balance - (For a particular type or stratum of nuclear material, e.g., UF_6 cylinders, trays of pellets) - the book inventory at any time, or the algebraic sum of the inventory at the beginning of a defined (examination) period and the inventory changes during the period, equalling the inventory at the end of that period.

133. Stratum - Grouping of items/batches having similar physical and chemical characteristics (e.g., volume, weight, isotopic composition, location, etc.) for the purpose of facilitating statistical sampling for measurements needed to establish and verify the material balance and its uncertainty (σ_{MUF}).

NOTE: The various components of a material balance are established by the facility operator on the basis of measurements. These same data are used by IAEA inspectors for verification purposes. Measurement procedures and the formulation of sampling plans can be simplified considerably if the different items and batches with similar characteristics are grouped into strata. Such groupings are also advantageous to facility operators for the purpose of determining the number of measurements needed to establish the material balance and compute its uncertainty (σ_{MUF}).

134. Material Balance Component - The combination of all strata in one term of the material balance equation. For example, arriving UF_6 cylinders and UO_2 powder in drums are combined as receipts component of the material balance equation.

135. Book Inventory - (of a material balance area) - "the algebraic sum of the most recent physical inventory of that material balance area and of all inventory changes that have occurred since that physical inventory was taken" [153/para. 102].

136. Physical Inventory - "the sum of all the measured or derived estimates of batch quantities of nuclear material on hand at a given time within a material balance area, obtained in accourdance with specified procedures" [153/para. 113].

137. MUF (Material-Unaccounted-For) - "the difference between book inventory and physical inventory" [153/para. 111]. The MUF equation is commonly written as:

$$MUF = PB + X - Y - PE$$

where components of the equation are

PB = beginning physical inventory for period j

X = sum of increases to inventory [receipts, nuclear production, de-exemption, correction to receipts, as appropriate]

Y = sum of decreases from inventory [shipments, nuclear loss due to radioactive decay or burn-up, exemption, measured discard, accidental loss, as appropriate]

PE = ending physical inventory period j, which is also the beginning of the physical inventory for period j + 1.

This formulation assumes that the increases X are measured by the receiver. If the increases are based on shipper's values an alternate formulation is

MUF = PB + S - SRD - Y - PE

where

S = the sum of the shipper's values

SRD = sum of the shipper/receiver differences (S -X).

138. Shipper/Receiver Difference - "the difference between the quantity of nuclear material in a batch as stated by the shipping material balance area and as measured at the receiving material balance area" [153/para. 114].

139. Adjustment - "an entry into an accounting record or a report showing a shipper/receiver difference or material unaccounted for" [153/para. 98].

140. Correction - "an entry into an accounting record or a report to rectify an identified mistake or to reflect an improved measurement of a quantity previously entered into the record or report. Each correction must identify the entry to which it pertains" [153/para. 103].

141. Unmeasured Loss - nuclear material contained in effluents which is disposed of from a material balance area without measurements.

142. Annual Throughput - "the amount of nuclear material transferred annually out of a facility working at nominal capacity" [153/para. 99]. This definition was originally used for

establishing the frequency and intensity of routine inspections in [153/para. 79, 80]. However, it is generally used for other purposes as well, e.g., to calculate MUF or σ_{MUF}. For facilities dominated by inventories rather than throughput (e.g., reactors) the ending physical inventory (PE) is commonly used for these purposes.

143. MUF Expected Value - the hypothetical, or "true" value of the MUF in the absence of measurement error.

144. MUF Observed Value - the value stated by the operator, based on the closing of a material balance for a given period. Whether or not diversion has occurred, the MUF for bulk material will normally be different from zero due to mistakes in accounting, measurement uncertainty, holdup in process equipment, and unmeasured losses. Even for item accounting the observed MUF may be different from zero because of errors in counting, especially where large numbers of items are involved, such as in an on-load fuelled reactor.

145. Inventory-Change (Flow) Verification - any activity conducted to confirm a recorded increase or decrease, in terms of batches, of nuclear material in a material balance area. It is the verification of inventory change as defined in [153/para. 107]. The principal reason for inventory change verification is that the uncertainty associated with these changes can represent a large part of the uncertainty in the material balance equation. Obviously, without verification of the increases, decreases and ending physical inventory, evaluation of MUF using the material balance concept is not possible.

146. Inventory Verificaion - any activity carried out to confirm the operator's recorded sum of measured values or derived estimates of batches of nuclear material on hand at a given time within a material balance area. The IAEA recognizes two types of inventory verification: the Physical Inventory Verification which coincides with closing a material balance period and physical inventory taking by the operator; and the Interim Inventory Verification which does not coincide with closing a material balance period and during which part or all of the inventory is verified.

147. Item Counting - establishment of the population of items in a batch, stratum or material balance component by counting the total number presented for verification.

148. Item Identification - examination of an identification marking affixed to an item or intrinsically part of that item for the purpose of verifying that the identification corresponds to that previously established and/or provided in the operator's records.

149. Dynamic Material Accountancy - a technology designed to achieve real-time accounting and control of nuclear material without undue obstruction to the operation of the facility. The dynamic material accountancy system employs in-plant non-destructive assay instrumentation, data acquisition, data base management and real time accountability. The objective of dynamic material accountancy is to enable the safeguards authority to make a more accurate and timely verification of the flow of nuclear material without obstructing facility operation.

APPENDIX II

SAFEGUARDS GLOSSARY, CHAPTER IX.

INFORMATION, RECORDS, REPORTS, INSPECTIONS

Information received from a State or provided by a facility, i.e., notifications, design information, various other reports and documents, and the records of nuclear material kept by facilities are the basis on which the IAEA builds to discharge its safeguards responsibility. In this regard, safeguards inspection is the most important procedure implemented to verify the completeness, correctness and validity of such information.

231. Accounting Records - a set of documents kept at each nuclear facility, showing the quantity of each type of nuclear material present, its distribution within the facility and any changes affecting it. The accounting records which are to be kept pursuant to safeguards agreements with the IAEA are stipulated in [66/para. 33, 34, 35] and [153/para. 56, 57].

232. Operating Records - a set of documents kept at each facility consisting of organized data on the operation of the facility in connection with the use or handling of nuclear material, e.g., the operating records of a nuclear reactor show the integrated thermal power produced by the reactor for a given period and the associated data of the reactor opertion for that period. The requirements for operating records are provided in [66/para. 33, 34, 35] and [153/para. 58].

233. Supporting Documents - records which contain identity data, source data and batch data for each accounting transaction;

they are, e.g., shipping documents, weight (volume) records, laboratory reports, charge/discharge and exposure records.

234. Initial Report - an official statement by the State to the IAEA on the status of nuclear material subject to safeguards pursuant to an agreement concluded in accordance with [153] at the time the agreement enters into force. The requirement for initial reports is provided in [153/para. 62].

235. Accounting Report - a statement to the IAEA on the status of nuclear material subject to safeguards in a defined environment and on the changes in that status since the previous report. Accounting reports are submitted by the State at times specified in the agreements or subsidiary arrangements. Under agreements concluded in accordance with [66] provision for accounting reports is made at [66/para. 37, 38, 39(a), 40]. Under [153] provision is made for:

236. Inventory Change Reports (ICR) "showing changes in the inventory of nuclear material. The reports shall be dispatched as soon as possible and in any event within 30 days after the end of the month in which the inventory changes occurred or were established" [153/para. 63(a)]. Also, "inventory change reports shall specify identification and batch data for each batch of nuclear material, the date of the inventory change and, as appropriate, the originating material balance area and the receiving material balance area or the recipient. These reports shall be accompanied by concise notes:

(a) Explaining the inventory changes, on the basis of the operating data contained in the operation records ... and

(b) Describing, as specified in the Subsidiary Arrangements, the anticipated operational programme, particularly the taking of a physical inventory" [153/para. 64].

The State reports each inventory change, adjustment and correction either periodically in a consolidated list or individually. "The inventory changes shall be reported in terms of batches; small amounts, such as analytical samples, as specified in the Subsidiary Arrangements, may be combined and reported as one inventory change" [153/para. 65].

237. Material Balance Reports (MBR) "showing the material balance based on a physical inventory of nuclear material actually present in the material balance area. The reports shall be dispatched as soon as possible and in any event within 30 days after the physical inventory has been taken. The reports shall be based on data available as of the date of reporting and may be corrected at a later date as required" [153/para. 63(b)]. It is provided that "the material balance reports shall include the following entries, unless otherwise agreed by the Agency and the State:

(a) Beginning physical inventory;

(b) Inventory changes (first increases, then decreases);

(c) Ending book inventory;

(d) Shipper/receiver differences;

(e) Adjusted ending book inventory;

(f) Ending physical inventory; and

(g) Material unaccounted for" [153/para. 67].

238. Physical Inventory Listing (PIL) "listing all batches separately and specifying material identification and batch data for each batch" [153/para. 67]. These listings are attached to each material balance report.

239. Operating Report - a statement to the IAEA on the operation of a facility in connection with use and handling of nuclear material. Operating reports are submitted by the State for facilities safeguarded pursuant to agreements concluded in accordance with [66]. The requirement for operating reports is provided at [66/para. 39(b)].

240. Special Report - a statement by the State to the IAEA on the loss of nuclear material exceeding specified limits or if containment and surveillance measures have been unexpectedly changed from those specified in the subsidiary arrangements. Agreements concluded in accordance with [66] also require special reports to be submitted in the event that a transfer of nuclear material results in a significant change in the inventory of a facility. The requirement for special reports is made at [66/para. 42, 43] and [153/para. 68].

241. Notification - requirement provided by agreements for information to be sent to the IAEA on international transfers of nuclear material, equipment and facilities as well as on transfers of safeguarded nuclear material, equipment or facilities within the State to a facility not previously subject to IAEA safeguards. Agreements concluded pursuant to [153]

provide that "any intended transfer out of the State of safeguarded nuclear material in an amount exceeding one effective kilogram, or by successive shipments to the same State within a period of three months each of less than one effective kilogram but exceeding in total one effective kilogram, shall be notified to the Agency after the conclusion of the contractual arrangements leading to the transfer and normally at least two weeks before the nuclear material is to be prepared for shipping. The Agency and the State may agree on different procedures for advance notification" [153/para. 92]. A similar provision but for transfers into the State, is made at [153/para. 95].

242. Inspection - a set of on-site IAEA activities to verify that the way in which nuclear material, equipment or facilities subject to safeguards are used complies with the provisions of the agreement. The activities may include: the review of design information to ensure that safeguards can be effectively applied, the examination of records of nuclear material and comparison with the corresponding statements by the State to the IAEA, inventory and flow verification, the installation and servicing of containment and surveillance devices.

[66/para. 51, 52] makes provision for initial inspection:

> "To verify that the construction of a pricipal nuclear facility is in accordance with the design reviewed by the Agency, an initial inspection or inspections of the facility may be carried out, if so provided in a safeguards agreement:

(a) As soon as possible after the facility has come under Agency safeguards, in the case of a facility already in operation; or

(b) Before the facility starts to operate, in the other cases.

The measuring instruments and operating characteristics of the facility shall be reviewed to the extent necessary for the pupose of implementing safeguards. Instruments that will be used to obtain data on the nuclear material in the facility may be tested to determine their satisfactory functioning. Such testing may include the observation by inspectors of commissioning or routine tests by the staff of the facility, but shall not hamper or delay the construction, commissioning or normal operation of the facility."

[66/para. 49] makes provision for routine inspections:

"Routine inspection may include, as appropriate:

(a) Audit of records and reports;

(b) Verification of the amount of safeguarded nuclear material by physical inspection, measurement and sampling;

(c) Examination of principal nuclear facilities, including a check of their measuring instruments and operating characteristics; and

(d) Check of the operations carried out at principal nuclear facilities and at research and development facilities containing safeguarded nuclear material."

[66/para. 53, 54] make provision for special inspections:

"The Agency may carry out special inspections if:

(a) The study of a report indicates that such inspection is desirable; or

(b) Any unforeseen circumstance requires immediate action.

The Board shall subsequently be informed of the reasons for and the results of each such inspection. The Agency may also carry out special inspections of substantial amounts of safeguarded nuclear material that are to be transferred outside the jurisdiction of the State in which it is being safeguarded, for which purpose the State shall give the Agency sufficient advance notice of any such proposed transfer."

[153/para. 71] makes provision for the IAEA to make ad hoc inspections in order to:

"(a) Verify the information contained in the initial report on the nuclear material subject to safeguards under the Agreement;

(b) Identify and verify changes in the situation which have occurred since the date of the initial report; and

(c) Identify, and if possible verify the quantity and composition of, nuclear material ... before its transfer out of or upon its transfer into the State."

[153/para. 72] makes provision for the IAEA to make routine inspections in order to:

"(a) Verify that reports are consistent with records;

(b) Verify the location, identity, quantity and composition of all nuclear material subject to safeguards under the Agreement; and

(c) Verify information on the possible causes of material unaccounted for, shipper/receiver differences and uncertainties in the book inventory."

[153/para. 73] makes provision for the IAEA to make special inspections:

"(a) In order to verify the information contained in special reports; or

(b) If the Agency considers that information made available by the State, including explanations from the State and information obtained from routine inspections, is not adequate for the Agency to fulfill its responsibilities under the Agreement."

243. Scope of Inspection - for the purposes of inspection under NPT agreements the IAEA may:

"(a) Examine the records kept ...;

(b) Make independent measurements of all nuclear material subject to safeguards under the Agreement;

(c) Verify the functioning and calibration of instruments and other measuring and control equipment;

(d) Apply and make use of surveillance and containment measures; and

(e) Use other objective methods which have been demonstrated to be technically feasible" [153/para. 74].

Within the scope of inspections "the Agency shall be enabled:

(a) To observe that samples at key measurement points for material balance accounting are taken in accordance with procedures which produce representative samples, to observe the treatment and analysis of the samples and to obtain duplicates of such samples;

(b) To observe that the measurements of nuclear material at key measurement points for material balance accounting are representative, and to observe the calibration of the instruments and equipment involved;

(c) To make arrangements with the State that, if necessary:

(i) Additional measurements are made and additional samples taken for the Agency's use;

(ii) The Agency's standard analytical samples are analyzed;

(iii) Appropriate absolute standards are used in calibrating instruments and other equipment; and

(iv) Other calibrations are carried out;

(d) To arrange to use its own equipment for independent measurement and surveillance, and if so agreed and specified in the Subsidiary Arrangements, to arrange to install such equipment;

(e) To apply its seals and other identifying and tamper-indicating devices to containments, if so agreed and specified in the Subsidiary Arrangements; and

(f) To make arrangements with the State for the shipping of samples taken for the Agency's use" [153/para. 75].

244. Access for Inspection - for the implementation of safeguards agreements concluded pursuant to [66] Agency

inspectors shall have access to all materials, equipment and facilities to which Agency safeguards are applied. This is specified in [39/para. III.9] which further provides that inspectors "shall have access at all times to all places and data and to any person, to the extent provided for in Article XII.A.6 of the Statute. The State shall direct all such persons under its control to cooperate fully with Agency inspectors" and shall identify and indicate the exact location of all safeguarded materials, equipment and facilities.

Agreements concluded pursuant to [153] provide that

(a) "... the Agency's inspectors shall have access to any location where the initial report or any inspections carried out in connection with it indicate that nuclear material is present;

(b) ... the inspectors shall have access to any location of which the Agency has been notified (in relation to shipments out of or into the State);

(c) ... Agency's inspectors shall have access only to the strategic points specified in the Subsidiary Arrangements and to the records maintained...; and

(d) in the event of the State concluding that any unusual circumstances require extended limitations on access by the Agency, the State and the Agency shall promptly make arrangements with a view to enabling the Agency to discharge its safeguards responsibilities in the light of these limitations. The Director General shall report each such arrangement to the Board" [153/para. 76].

The Agreement also provides that in circumstances which may lead to special inspections the State and the Agency shall consult forthwith. As a result of such consultations the Agency may make inspections in addition to the normal routine inspections and may obtain access to additional agreed information or locations (See [153/para. 77]).

245. Simultaneous Inspections - inspections carried out by IAEA inspectors simultaneously or within a short period of time at two or more facilities in a State in order to detect possible diversions arranged in collusion between facilities by, e.g., the temporary transfer of nuclear material between facilities so that the same material will be verified twice by the IAEA, once in each of two successively inspected facilities. The facilities may be of the same kind, e.g., light water reactors using the same type of fuel assemblies; or facilities linked in the same fuel cycle, e.g., light water reactors, fuel fabrication and reprocessing plants, spent fuel storage areas etc.

246. Continuous Inspection - the maximum case of an inspection regime intended to maintain continuity of knowledge concerning inventory and flow of nuclear material by witnessing key operations and recording measurement and operations data directed at verifying the data and information obtained to meet the objectives of timely detection. The activities involved may or may not require the continuous presence of inspector(s) within the facility. At a reprocessing plant for example, where continuous inspection is usually carried out, inspectors are

present during the day shift and are on call for the remaining shifts. During the latter, inspectors are called whenever important operations are to be carried out by the operator, e.g., volume and density measurements in accountancy tanks, the transfer of product solutions or any other inventory changes that occur between material balance areas.

[66] provides in Annex I, para. 3 and Annex II, para. 3 for continuous inspection for reprocessing plants and conversion and fabrication plants respectively. For facilities safeguarded pursuant to agreements concluded in accordance with [153] the inspection effort allowed under [153/para. 80] may in practice result in continuous inspection.

247. Unannouced Inspection - [66/para. 50] makes provision for the IAEA to carry out unannounced inspections: "Whenever the IAEA has the right of access to a principal nuclear facility at all times, it may perform inspections of which notice as required by paragraph 4 of the Inspectors Document need not be given, in so far as this is necessary for the effective application of safeguards. The actual procedures to implement these provisions shall be agreed upon between the parties concerned in the safeguards agreement."

[153/para. 84] provides that: "as a supplementary measure, the Agency may carry out without advance notification a portion of the routine inspections ... in accordance with the principle of random sampling. In performing any unannounced inspections, the Agency shall fully take into account any operational programme provided by the State ... . Moreover, whenever practicable, and on the basis of the operational programme, it shall advise the State periodically of its general programme of announced and unannounced inspections, specifying the general periods when inspections are foreseen. In carrying out any unannounced inspections, the Agency shall make every effort to minimize any practical difficulties for facility operators and the State ... . Similarly the State shall make every effort to facilitate the task of the inspectors."

248. Frequency of Inspection - a term used to describe inspection intensity by specifying the number of times per year (or per other unit of time) that a facility is to be inspected. The term does not extend to cover the number of inspectors, the inspection activities they perform, or the number of man-days such activities require. The Maximum Inspection Frequency (MIF) of routine inspections is the maximum number of inspections allowable per year for principal nuclear facilities, research and development facilities and safeguarded nuclear material in other locations in terms of agreements under [66].

249. Man-day - "a day during which a single inspector has access to a facility at any time for a total of not more than eight hours" [153/para. 109].

250. Maximum Routine Inspection Effort (MRIE) - the maximum number of man-days or man-years of inspection per annum allowable for a facility as provided in [153/para. 80].

251. Actual Routine Inspection Effort (ARIE) - the inspection effort expressed in man-days per annum agreed for a facility between the IAEA and the State. The ARIE is equal to or

less than the MRIE. The agreed ARIE is included in the facility attachment of the subsidiary arrangements.

252. IAEA Inspectors - IAEA officers appointed by the Director General and approved by the Board of Governors of the IAEA to perform safeguards inspections. After approval by the Board, the inspectors are proposed to the States in which they are expected to operate. If the State agrees, the IAEA effects the designation. Inspectors are granted privileges and immunities necessary for the performance of their functions pursuant to Articles VI and VII of the agreement on the Privileges and Immunities of the IAEA [9].

253. IAEA Inspection Report - an internal report by IAEA inspectors, reflecting the activities performed and the results of an inspection. The report serves as the basis for evaluation and may contain a quantitative statement about a partial or complete inventory verification made during the inspection.

254. Statement - an official communication by the IAEA to a State, indicating the results of an inspection carried out in the State or the conclusions the IAEA has drawn from its verification activities. Paragraph 12 of The Inspectors Document [39] provides for statements by the IAEA to States after inspections have been carried out pursuant to an agreement in accordance with [66].

[153/para. 90] provides for statements by the IAEA to States on the results of inspections and the conclusions the IAEA has drawn from its verification activities.

255. Safeguards Implementation Report (SIR) - an annual report by the Director General of the IAEA to the Board of

Governors. It summarizes the performance of IAEA safeguards activities and includes:

- a safeguards statement concerning the IAEA's conclusions about the occurrence or non-occurrence of diversion or other violations of safeguards agreements in States in which IAEA safeguards were applied;
- an evaluation of safeguards effectiveness in terms of the IAEA safeguard objectives; and
- an identification of implementation difficulties and corresponding action plan to overcome the difficulties.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #9: INTRODUCTION TO NUCLEAR FUEL CYCLES

The basic features of nuclear fuel cycles and the fissionable materials that fuel nuclear reactors will be surveyed. The associated movement of nuclear materials within the fuel cycle and the different types of safeguards that are applied to them will be reviewed and discussed.

After the session, participants will be able to

1. Describe the basic components of existing and potential nuclear fuel cycles.

2. Identify fuel-cycle facilities and transportation steps for which nuclear safeguards are most necessary.

3. Differentiate among the safeguards roles of materials accountancy, material control, and physical protection.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #9: INTRODUCTION TO NUCLEAR FUEL CYCLES

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Thursday, May 29, 1980
8:30 a.m.

BIOGRAPHY

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Present Position: Associate professor of Nuclear Engineering; University of New Mexico (1974-). Teach basic nuclear engineering, reactor theory, safety and safeguards; research in safety and safeguards.

Past Positions: Senior physicist in reactor physics and computational analysis, Combustion Engineering 1972-74.

Director, seven short courses on nuclear criticality safety. Faculty member, International Training Course on Physical Protection (Albuquerque, NM, 1978 and 1979). Author, NUCLEAR ENERGY TECHNOLOGY, McGraw-Hill (Late 1980)

SESSION 9: INTRODUCTION TO NUCLEAR FUEL CYCLES

Prof. Ronald Knief
University of New Mexico

I. OVERVIEW

This session is intended to provide a relatively brief overview of the dominant features of existing and near-future nuclear fuel cycles. Emphasis is placed on the uranium cycles of light-water reactors (LWR) and heavy water reactors (HWR) including the potential for plutonium recycle operations.

The roles of various nuclear safeguards measures are summarized. Their general applications to specific fuel cycle steps are considered in terms of material forms, quantities and waste streams.

II. THE NUCLEAR FUEL CYCLE

A. Introduction

The production of energy from any fuel material is based on a fuel cycle. Typical cycles, such as those for the fossil fuels, consist of at least the following components:

(1) exploration to identify the compositions and amounts of a resource available at various locations;

(2) mining or drilling to bring the resource to the earth's surface in a usable form;

(3) processing or refining to convert raw materials into a final product;

(4) consumption of the fuel for energy production;

(5) disposal of wastes generated in all portions of the cycle; and

(6) transportation of materials between the various steps of the cycle.

The nuclear fuel cycle is substantially more complicated for the following reasons:

(1) ^{235}U, which is the only practical naturally-occurring fissile material, is less than one percent abundant in all known uranium deposits (the remaining uranium is fertile ^{238}U);

(2) two other fissile materials, ^{233}U and ^{239}Pu are produced by neutron bombardment of ^{232}Th and ^{238}U, respectively (for this reason the latter two materials are said to be fertile);

(3) all fuel cycle materials contain small to large amounts of radioactive constituents;

(4) a neutron chain reaction (criticality) could occur outside of a reactor under appropriate conditions; and

(5) the same chain reaction that can be used for commercial power generation also has potential application to a nuclear explosive device.

Each of these five concerns has an important impact on the design and operation of nuclear fuel cycles.

The basic features of the uranium fuel cycle for the light-water reactor bear many similarities to those of other fuel cycles. A few important differences exist in the heavy-water reactor fuel cycle. More complex fuel cycles include both uranium and thorium.

B. LWR Fuel Cycle

A schematic representation of the uranium fuel cycle is shown in Figure 1. This cycle is employed for the light-water

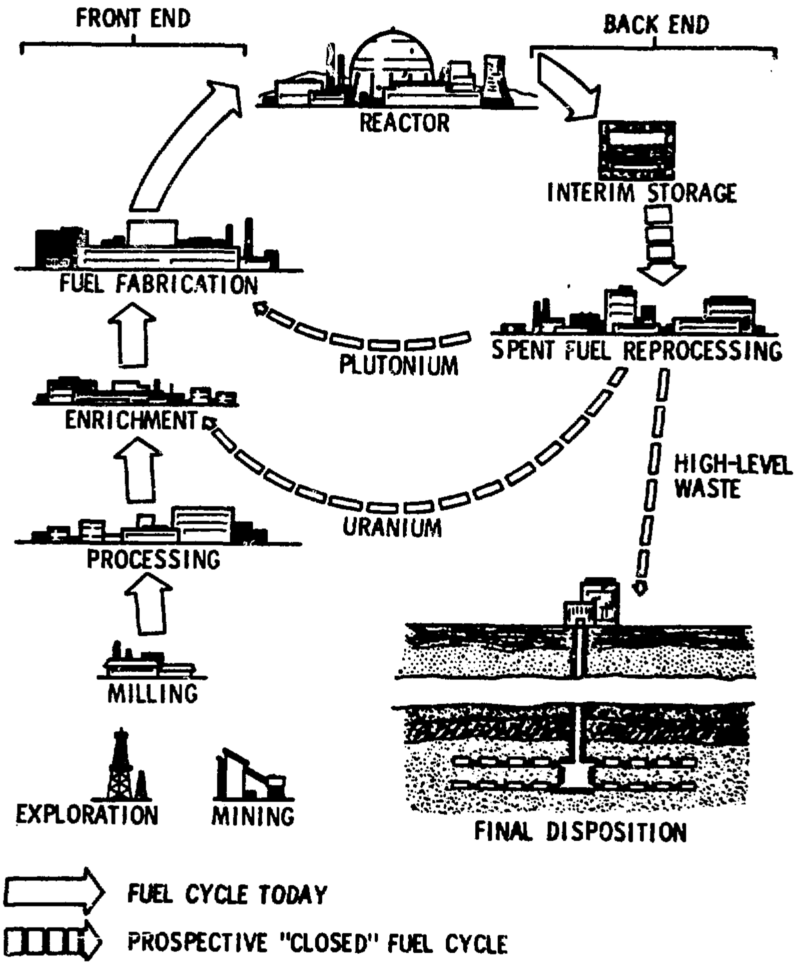

Figure 1. Uranium Fuel Cycle for a Light Water Reactor

reactor [LWR] systems which currently dominate world-wide nuclear power. The solid arrows in Figure 1 connect components of the presently "open" c~~le that exists in the United States. The dashed arrows show pathways that would complete, or "close", the uranium fuel cycle.

One inherent step of the fuel cycle which is not named explicitly on Figure 1 is recycle of plutonium and uranium. Transportation between the various steps is indicated by the arrows. Waste disposal from operations other than reprocessing is not shown explicitly.

Nuclear safety, the protection of operating personnel and the public from potentially hazardous materials in the fuel cycle, must be superimposed on appropriate portions of the cycle. Also superimposed are material safeguards to preclude use of fuel cycle materials for nuclear explosives.

The steps preceding reactor use, which generally have little radioactivity, are often considered to form the front end of the fuel cycle. Those that follow reactor use are characterized by high radiation levels and are said to be part of the back end of the cycle.

1. Exploration. The exploration process typically begins with geologic evaluation to identify potential uranium deposits. Areas which have characteristics similar to those of known content usually receive first consideration. The actual presence of uranium may be verified by chemical and/or radiological testing.

Drilling into the deposit accompanied by detailed analysis of the samples provides information on uranium ore composition and location. Only after completion of a very detailed mapping of the ore body will mining operations begin.

2. Mining. Uranium may be mined by open-pit (strip mining) or underground operations, depending upon the nature of the deposit. Major world-wide resources are located in the United States, Australia, Canada, South Africa, and the U.S.S.R.

A few deposits have been found which have assays of as high as 10 percent uranium metal content. However, most deposits have assays on the order of a few tenths of 1 percent uranium. Despite the low fractional content, uranium ore is 30-50 times more efficient than coal on the basis of "energy per ton mined." Since many environmental impacts are proportional to the amount of ore removed, clear advantages for nuclear energy may accrue here.

3. Milling. One type of milling operation removes uranium from the ore by employing the following steps:

a. crushing and grinding of ore to optimum size;

b. leaching in acid to dissolve the metals away from predominantly non-metal ore content;

c. ion-exchange or solvent-extraction operations to separate uranium from other metals; and

d. production of U_3O_8, usually in the form of yellow cake, so named because of its color.

The major problems associated with milling operations are related to chemical effluent releases and some radioactivity in the ore residues [tailings].

4. Conversion and Enrichment. Natural uranium is composed of fissile ^{235}U, (.711 wt%), ^{238}U (99.3 wt%), and trace amounts of ^{234}U and ^{236}U. Since many reactor concepts require that the ^{235}U fraction of the total uranium content be higher than this enrichment, separation of the isotopes by physical means has been implemented.

The conversion step begins by purifying the U_3O_8 [yellow cake]. Then, through chemical reaction with fluorine, uranium hexafluoride [UF_6] is produced.

UF_6 -- a gas at temperatures above 56°C [134°F] at atmospheric pressure -- is readily employed in one of several enrichment schemes. The gaseous diffusion method which has been the world's "workhorse" is based on forcing UF_6 against a porous barrier. The lighter $^{235}UF_6$ molecules penetrate the barrier more readily than do the heavier $^{238}UF_6$ molecules. (According to the kinetic theory of gases, each molecule has the same average kinetic energy,so that greater speed and, thus, barrier penetration probability, belongs to the lighter molecule.) By cascading the barrier stages, any desired enrichment can be obtained. At the present time, slightly-enriched uranium at 2-4 wt% ^{235}U is produced for LWR use. The uranium left behind in the process is called the depleted stream (or "enrichment tails") and is typically 0.2-0.35 wt% ^{235}U.

The gas centrifuge process is becoming an increasingly popular enrichment technology. Like gaseous diffusion it exploits the slight mass difference between the ^{235}U and ^{238}U constituents of the UF_6 gas. Use of a high-speed centrifuge provides separation as the heavier $^{238}UF_6$ is pushed preferentially toward the outside of the device. Appropriate interconnection of units can also produce enrichment to essentially any desired level.

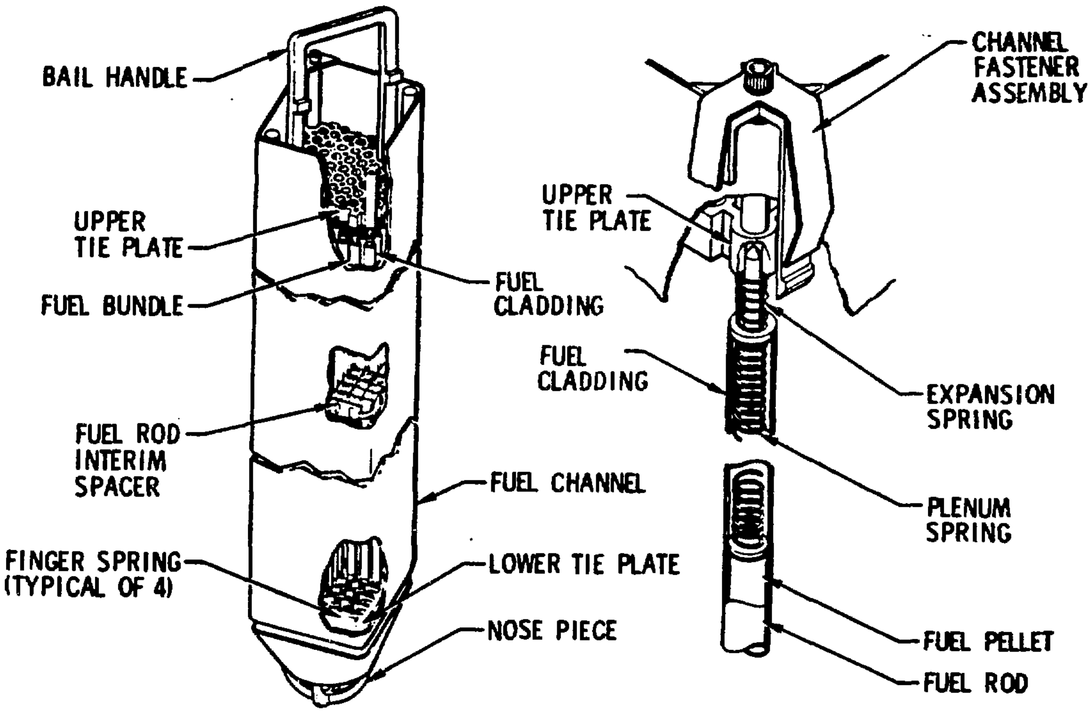

Figure 2. Typical fuel assembly for a boiling water reactor (courtesy General Electric Co.)

5. Fabrication. The fabrication step of the cycle produces fuel in the final form that is used for power production in the reactor. LWR fabrication begins by converting the

slightly-enriched uranium hexafluoride to uranium dioxide [UO_2], a black ceramic composition. The UO_2 powder is then formed into cylindrical pellets roughly the size of a thimble.

The pellets are loaded into long cladding tubes to form individual fuel pins. The final fuel assembly consists of an array of fuel pins plus some other hardware. Fuel assemblies for the two major types of light-water reactors, the boiling water reactor (BWR) and the pressurized-water reactor (PWR), are shown in Figures 2 and 3, respectively.

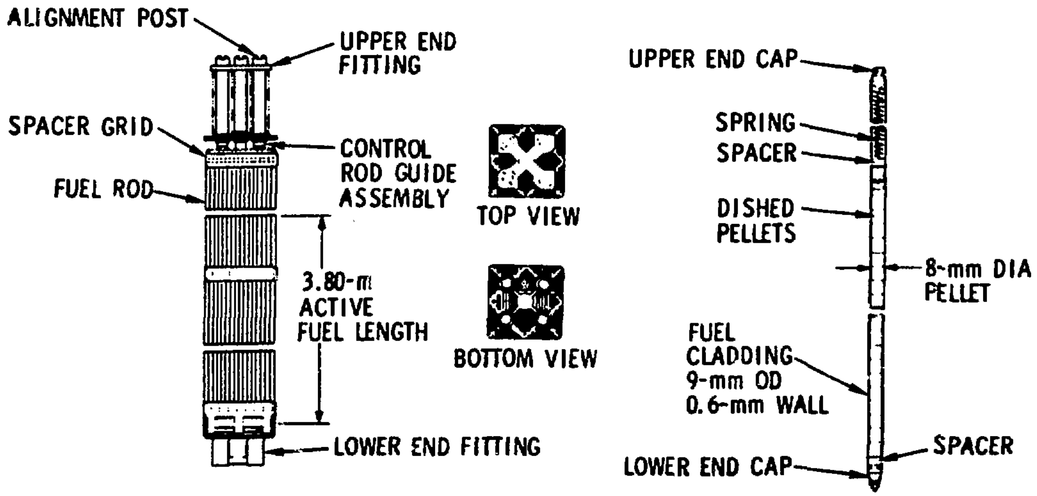

Figure 3. Typical fuel assembly for a pressurized water reactor (courtesy Combustion Engineering, Inc.)

6. <u>Reactor Use</u>. The fuel assemblies are loaded into a reactor vessel where the fission process is initiated. Coolant water pumped through the vessel removes heat energy from the fuel. In the BWR, boiling occurs directly in the vessel. The

PWR, on the other hand, does not allow in-core boiling, but does produce steam by energy transfer in an external heat exchanger or steam generator. The steam is ultimately employed for production of electricity in both systems. Typical vessels for the two types of light water reactors are shown by Figures 4 and 5, respectively.

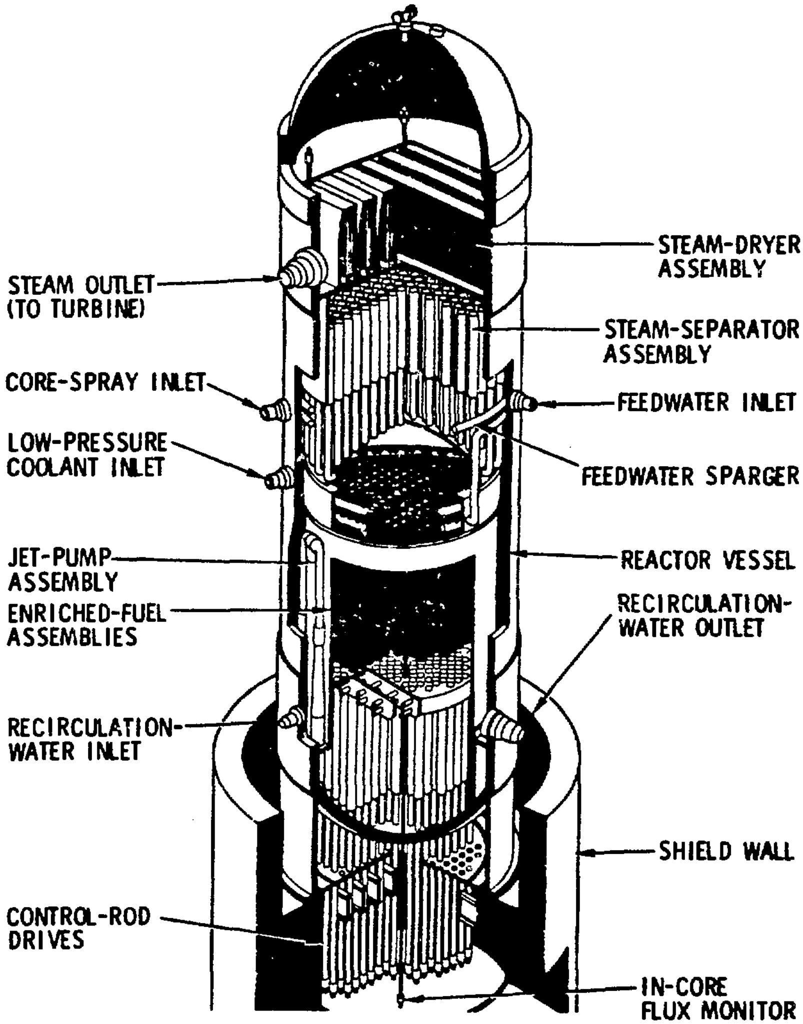

Figure 4. Typical reactor vessel for a BWR (courtesy Scientific American (1))

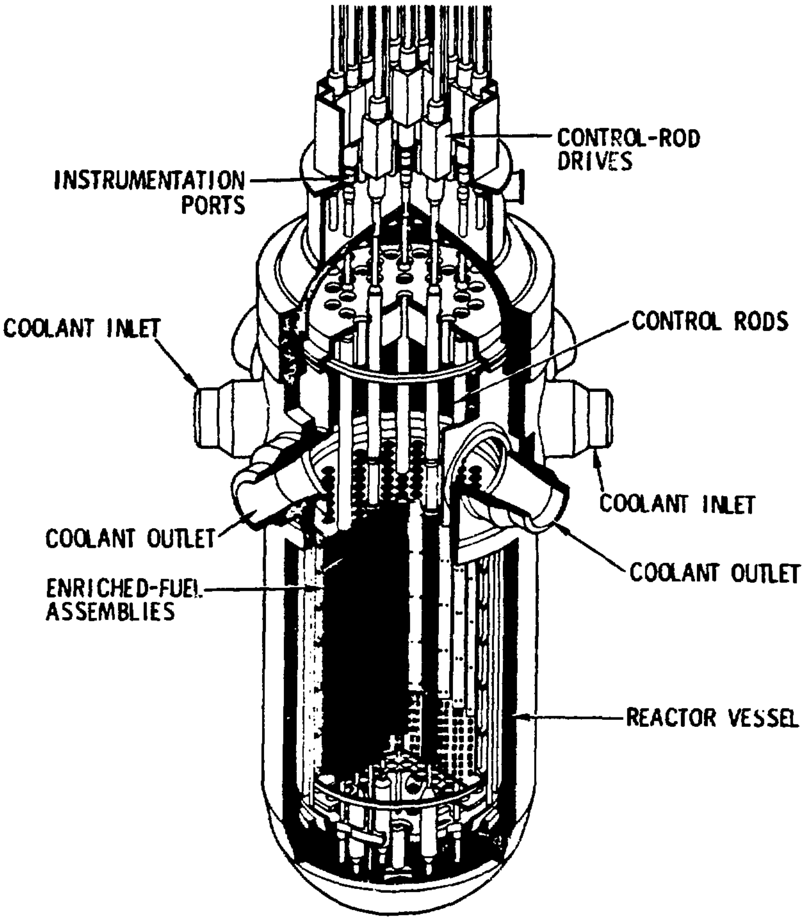

Figure 5. Typical reactor vessel for a PWR (courtesy Scientific American (1))

With continued fission of the fuel, the system loses its ability to sustain the fission rate due to depletion of fissile ^{235}U and the build-up of fission products which act as "poisons." Although the depletion effect is partially offset by production ("breeding") of fissile plutonium from ^{238}U, the reactor eventually loses its ability to sustain the fission chain reaction.

At present, standard procedure at a light water reactor is to remove the vessel head and replace one-fourth to one-third of the fuel assemblies on an approximately annual basis. Careful fuel management can maximize energy extraction from each fuel batch during the 3 to 4 years it remains in the reactor core.

7. Interim Spent Fuel Storage. Spent fuel assemblies are very highly radioactive when discharged from the reactor. Interim storage in an on-site water basin allows both the radiation and heat production levels to decrease through the natural radioactive decay process. After a reasonable amount of storage time has been expended, the spent fuel assemblies may be transported to a reprocessing facility. If the spent fuel is not to undergo reprocessing, it can be stored indefinitely at the on-site facility or at a designated off-site facility.

8. Reprocessing. It is possible to reprocess spent fuel in order to extract residual uranium and the bred plutonium for further use in the fuel cycle. The fission-product and actinide wastes produced are handled in the waste disposal step.

In the initial steps of the reprocessing operations, the fuel assemblies are mechanically disassembled (i.e., chopped into small pieces) and dissolved in acid. The uranium and plutonium are separated from the wastes, then separated from each other. The large amounts of highly radioactive by-products contained in the spent fuel necessitate very stringent environmental controls for the processing steps and the storage of wastes.

9. Recycle. The residual uranium and the plutonium extracted from the spent fuel by the reprocessing operation may be reintroduced into the fuel cycle. Use of these recycled materials can reduce uranium resource requirements by up to 25 percent. The residual uranium is returned to the fuel cycle for re-enrichment. The plutonium is returned to the fabrication operation where it is mixed with depleted uranium to produce a mixed oxide with a fissile content roughly comparable to that of slightly enriched uranium.

10. Waste Disposal. All steps in the fuel cycle (including the waste disposal step itself) produce radioactive waste. Prior to reactor use, the wastes are "low-level." Reactor use produces "high-level" wastes in the form of spent fuel or reprocessing solutions.

If spent fuel is reprocessed, it is likely that the waste solutions would be stored as liquids for a period of time on the order of five years to allow for decay of some of the radioactivity. The waste would then by solidified and stored on-site for an additional period of time.

Solid wastes, such as spent fuel or solidified reprocessing wastes, will ultimately be transferred to a repository (probably government-operated) for final disposal. Final disposal is likely to be in a stable geologic formation or in the seabed.

11. Transportation. Since the various fuel cycle operations take place at a number of different locations, transportation is a very important component. The design and

operation of effective transportation systems should minimize the risks of:

- release of dangerous chemical or radioactive materials to the environment;
- accidental nuclear chain reaction outside of a reactor core;
- damage to expensive components; and
- theft of valuable and potentially dangerous materials.

Based on the nature of these risks, specially-designed containers and/or vehicles may be used between various steps of the fuel cycle.

12. Nuclear Safety. Nuclear safety in fuel cycle facilities is usually divided into categories of radiation safety and nuclear criticality safety. The former includes shielding and containment of radiation sources plus effluent control to minimize exposures to operating personnel and the general public.

Reactors are designed to handle the effects of a fission chain reaction while fuel-cycle facilities generally are not so designed. Thus, nuclear criticality safety is charged with prevention of such chain reactions in all environments outside of reactor cores. Since accidental criticality is not credible for natural uranium, these safety concerns begin at the enrichment step (Figure 1).

13. Material Safeguards. All fissile materials have potential use for nuclear explosives and must, therefore, be safeguarded against theft or diversion. Physical-protection, material-control, and material-accountancy systems are designed

to minimize the terrorist threat for theft by a sub-national group. International safeguards based on inventory verification have been developed to deter proliferation, i.e., diversion by a nation for the purpose of acquiring nuclear-weapons capability.

Safeguards measures should be commensurate with the risks perceived for given materials. The slightly-enriched uranium in the LWR fuel cycle, for example, could only be used for a nuclear explosive if it were enriched further. The extreme complexity of the enrichment technology would seem to make implementation of the required clandestine operations highly unlikely.

Since spent fuel contains fissile plutonium which can be separated chemically, it is a somewhat more attractive target. Only a national effort, however, would seem to be able to handle the complexity and hazard (as well as detectability) of reprocessing operations.

By contrast, recycle with the presence of separated plutonium would appear to offer the best theft target for the terrorist or other sub-national groups. Material safeguards measures, therefore, should be most stringent for this portion of the fuel cycle.

C. HWR Fuel Cycle

Compared to the LWR, the CANDU (Canadian Deuterium Uranium) heavy water reactors (HWR) are the next most popular systems around the world. Their design allows use of the uranium fuel in the natural rather than enriched form. Thus the CANDU fuel cycle is similar to that in Figure 1 except that no enrichment is required (and UF_6 is not produced in the conversion or refining steps).

The typical CANDU fuel assembly shown in Figure 6 consists

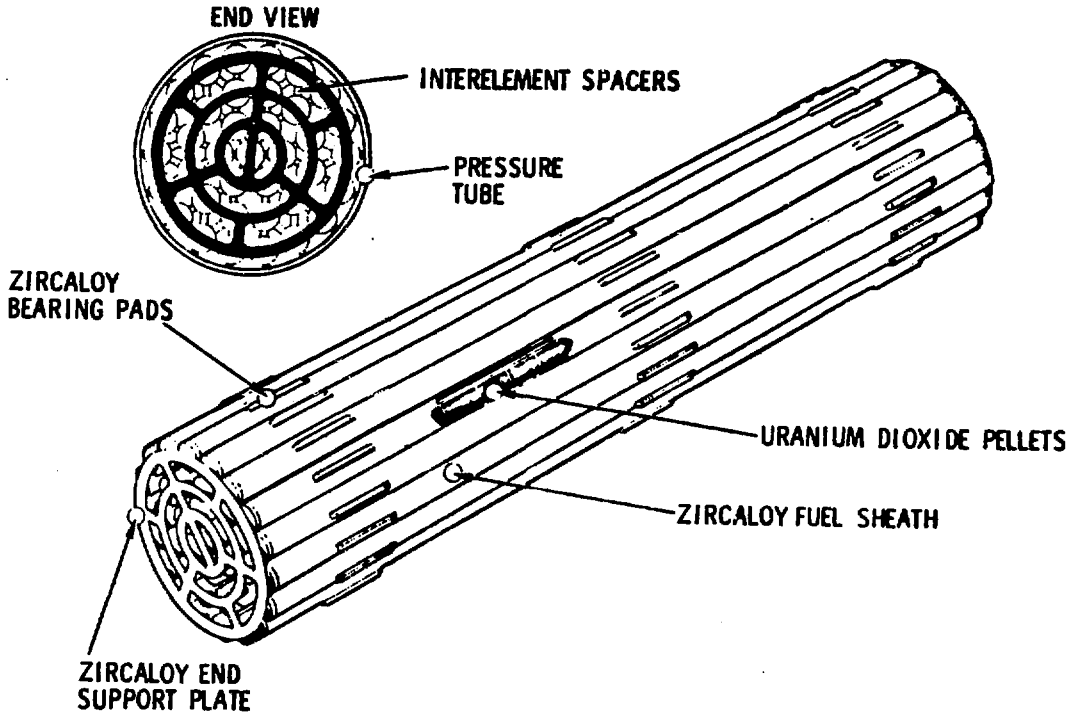

Figure 6. Typical fuel bundle for a CANDU heavy-water reactor (courtesy Atomic Energy of Canada Limited)

of UO_2 pellets and cladding like its LWR counterparts. However, it is cylindrical in shape and substantially smaller than those in Figures 2 and 3. This design is consistent with the use of heavy water as a coolant and with on-line refueling.

While the LWR systems can be refueled only when shutdown and with the vessel head removed, the CANDU has the capability to exchange fuel bundles while the reactor is operating. This is

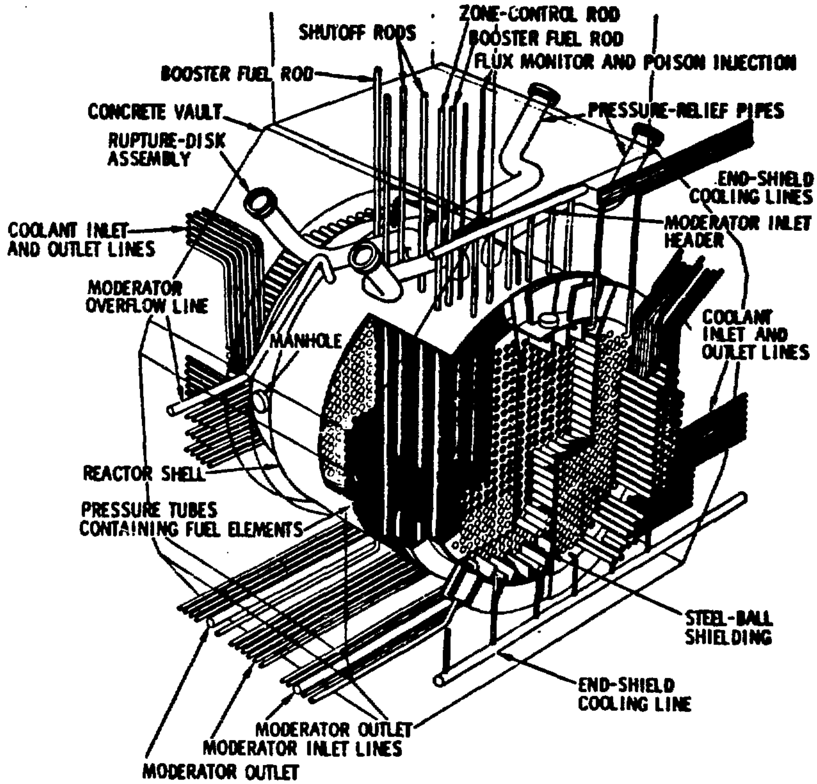

Figure 7. CANDU reactor vessel (courtesy Scientific American (1))

facilitated by the pressure tube design of the vessel shown in Figure 7. Heavy-water coolant flows only through the pressure tubes where the fuel bundles reside. As in the PWR, coolant boiling does not occur in the vessel, but steam is produced in an external steam generator.

A special refueling machine, shown in Figure 8, has been designed to attach simultaneously to both ends of any pressure tube. It allows coolant flows to be maintained as a fresh

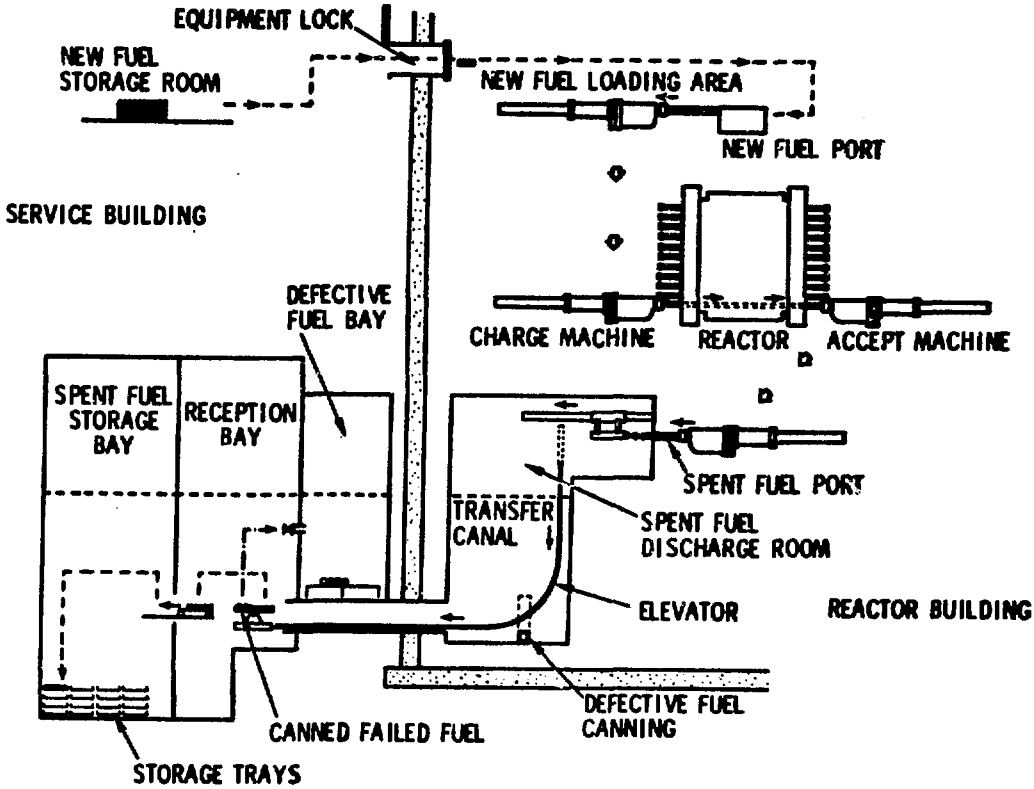

Figure 8. Refueling and spent fuel handling sequence for a CANDU reactor (courtesy Atomic Energy of Canada Limited)

bundle is pushed through from one end to force another out the opposite end. Spent fuel bundles are then stored in a water basin according to the sequence shown by Figure 8.

D. Generic Fuel Cycle

The basic uranium fuel cycle in Figure 1 may be modified by adding a thorium fuel stream to facilitate production of fissile

^{233}U from ^{232}Th. As shown in Figure 9, the major differences are related to thorium mining, processing, and fabrication operations plus the possibility for ^{233}U recycle.

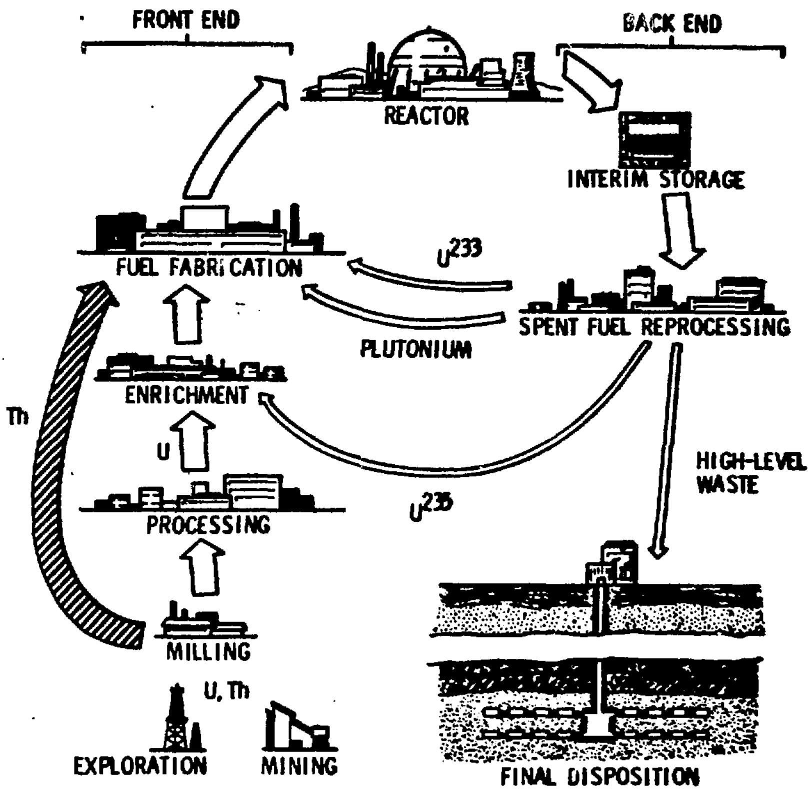

Figure 9. Generic fuel cycle with uranium and thorium product flows (Ref 2)

Modified LWR and HWR designs, as well as a number of advanced reactor concepts, are capable of using some combination of uranium and thorium with plutonium and ^{233}U recycle. Complex symbiotic or crossed-progeny cycles are also possible if recycle fuels are exchanged among one or more reactor types. Such cycles may have particular safeguards advantages because the nuclear material forms most useable for weapons could be excluded from certain facilities without denying any nation the benefits of nuclear power.

III. GENERAL SAFEGUARDS CONSIDERATIONS

In their most general form, safeguards are considered to be those measures designed to deter, prevent, delay, detect, and report the diversion of nuclear materials. Although both sub-national and national groups may be attributed the capabilities to design and construct a nuclear device, the emphasis of safeguards is fundamentally different for the two.

A. Domestic Safeguards

Diversion of nuclear material by domestic or sub-national groups is a matter of national security and is the purview of the State's System of Accountancy and Control (SSAC). Desired features include:

(1) accounting and detection systems capable of identifying and responding to attempted theft by insiders, and

(2) a physical security system capable of deterring or preventing a forcible attack by outsiders.

Viewed another way, the domestic safeguards system may be divided into physical protection, material accounting, and material control functions. According to the U.S. Nuclear Regulatory Commission one set of definitions is as follows:

Physical Protection is that part of the safeguards program encompassing the equipment, procedures, and physical controls to: (1) protect nuclear materials from theft or diversion through the use of access and egress controls and physical barriers, (2) detect attempts at theft or diversion through the use of surveillance measures and alarm systems, and (3) respond to attempts at theft or diversion through the use of on-site security personnel and off-site law enforcement assistance. Material Accounting is that part of the safeguards program encompassing the procedures and systems to: (1) perform nuclear material measurements, (2) maintain records, (3) provide reports, and (4) perform data analysis to account for nuclear material. Material Control is that part of the safeguards program encompassing management and process controls to: (1) assign and exercise responsibility for nuclear material, (2) maintain vigilance over the material, (3) govern its internal movement, location, and utilization, and (4) monitor the inventory and process status of all nuclear material.

B. International Safeguards

National diversion of material from a nuclear fuel cycle for the purpose of developing nuclear devices is the major concern of international safeguards. If such diversion leads to a first-time weapons capability, proliferation is said to have occurred.

As described earlier in this course, the Statute of the International Atomic Energy Agency (IAEA) and various agreements between countries serve as the basis for limiting the spread of nuclear weapons. The objective of IAEA safeguards has been set forth as "the timely detection of diversion significant quantities of nuclear material from peaceful nuclear activities... and the deterrence of such diversion by the risk of early detection."(3)

IAEA safeguards are to be employed "in a manner designed to avoid hampering a state's economic and technological development" and "to be consistent with prudent management practices required for the economic and safe conduct of nuclear activities."(4) Under these guidelines, verification of the state's system of nuclear material accountancy has become the safeguards measure of primary importance. Increasing use of containment and surveillance measures serve to augment the accountancy. Effective containment reduces the necessity for continuous reverification of affected materials. Surveillance can identify significant movements of material for which prompt inventory verification is appropriate.

1. Effectiveness. The overall effectiveness of IAEA safeguards must be correlated to the risks of proliferation associated with the various types, quantities, and forms of nuclear materials present in particular facilities. Safeguards objectives may be formulated in terms of nuclear material quantities and timeliness of detection based on the required processing. The uranium products in the LWR and HWR fuel cycles (Figure 1) are all natural or low-enriched and require isotopic enrichment for use in a nuclear device. On the other hand, spent fuel would require reprocessing while separated plutonium would require only chemical processing. In thorium cycles (Figure 9), separated ^{233}U could also be used after some chemical processing.

Significant quantities of nuclear material are estimated to be 8 kg of plutonium and of uranium-233, 25 kg of uranium-235 contained in uranium enriched to 20% or more in this isotope, 75 kg of uranium-235 contained in uranium of less than 20% enrichment (including natural and depleted uranium), and 20 metric tonnes of thorium. Since the IAEA must consider the possibility of diversion by the state, these are the quantities which should be detected by IAEA safeguards if diverted or otherwise missing within a state.

The goals for detecting (and reporting) diversion of such quantities should be relatively short times, i.e., one to three weeks, depending upon the chemical form and purity for plutonium, uranium-233 and enriched (20% or more) uranium. For irradiated fuels, detection-time goals should be two months and for uranium (less than 20% ^{235}U) and for thorium about one year.

The degree to which these objectives or goals can be attained at any time are a function of such factors as the resources available to the IAEA safeguards system and the state of development of safeguards technology. The degree to which goals can be approached with current capabilities provides the impetus for defining increased resource requirements and research and development needs. Safeguards goals are a means of assessing safeguards systems, not criteria that must be met at the present time.

2. Termination of Safeguards. Measurement of the nuclear material content of recycle and waste streams is an extremely important part of overall process accounting. It is also vital

to the extent that such streams would be logical pathways for diversion.

Once the content of waste streams has been verified, the potential for recovery of the nuclear materials also becomes an important safeguards consideration. Safeguards may be terminated on certain streams for which recovery is not deemed feasible.

An important IAEA provision, which addresses the termination of safeguards, states that "Nuclear material shall no longer be subject to safeguards upon determination by the Agency that it has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards or has become practicably irrecoverable."(4) However, the degree of dilution or extent of irrecoverability which would result in the termination of safeguards are not defined.

It is also possible that special safeguards arrangements may be allowed where the conditions in the above paragraph are not met. If the state considers that the recovery of safeguarded nuclear material from residues is not (for the time being) practicable or desirable, the IAEA and the state can reach an agreement on the appropriate safeguards measures to be applied. At the present time, this principle may be applied to retained waste which is considered irrecoverable and is stored at a material balance area (MBA) without being part of the inventory of that area.

With the exception of spent fuel assemblies, all waste streams in the LWR and HWR fuel cycles may meet termination criteria because the contained nuclear material is not recoverable with current technology in an economical manner. The further treatment and packaging of these wastes would make recovery even more difficult.

IV. MATERIAL FLOWS

The quantities of nuclear material in the fuel cycles have a major impact on the design and operation of the integrated material accounting systems that will be described later in the course. Typical material flows and quantities for four fuel cycle options are provided below for reference purposes.

The yearly LWR mass flows for a once through (i.e., no reprocessing) cycle shown in Figure 10 are for a typical pressurized water reactor (E = burnup, η = thermal efficiency, L = load factor). Those in Figure 11 are for the recycle case.

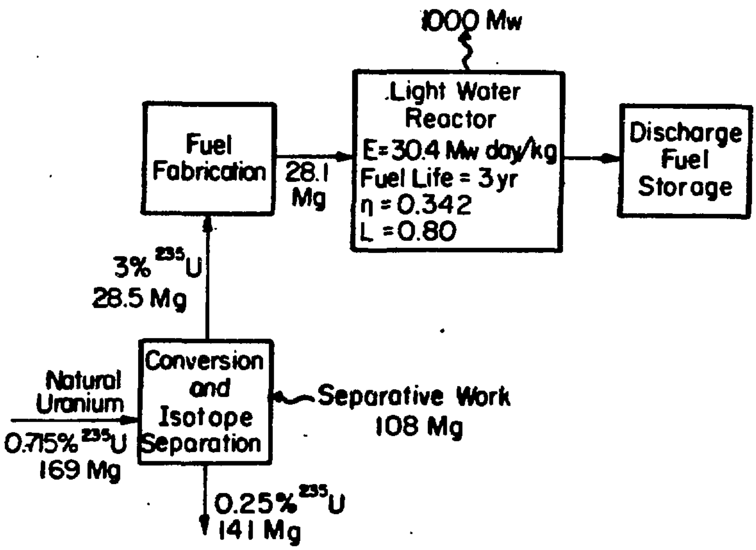

Figure 10. Annual material flow for a 1000 MW(e) PWR with no reprocessing (from Ref. 5). Mg ≡ million grams ≡ Metric Tonne.

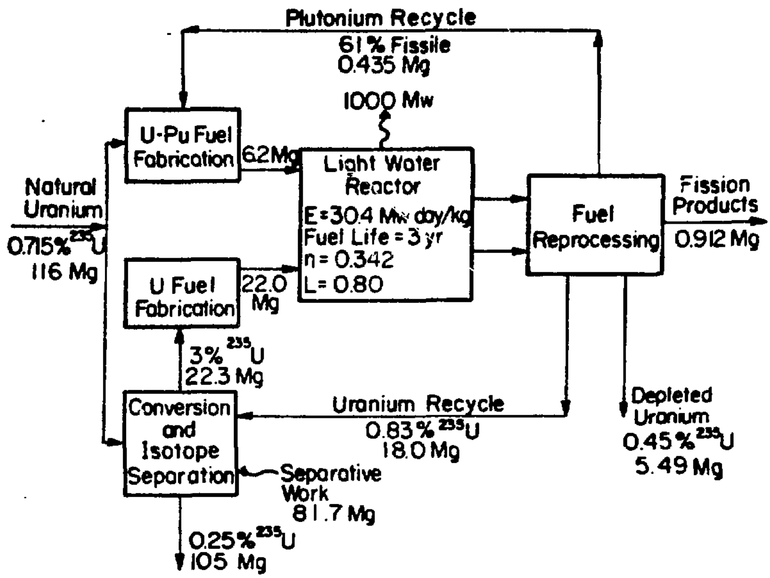

Figure 11. Annual material flow for a 1000 MW(e) PWR with U-Pu recycle (from Ref. 5)

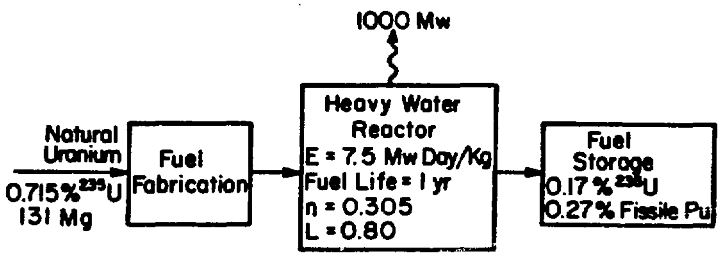

Figure 12. Annual material flow for a 1000 MW(e) CANDU with no reprocessing (from Ref. 5)

The HWR mass flows for a once-through cycle shown in Figure 12 are typical of a CANDU reactor. Those in Figure 13 are for the plutonium recycle case (since enrichment is not part of this fuel cycle, uranium is not recycled).

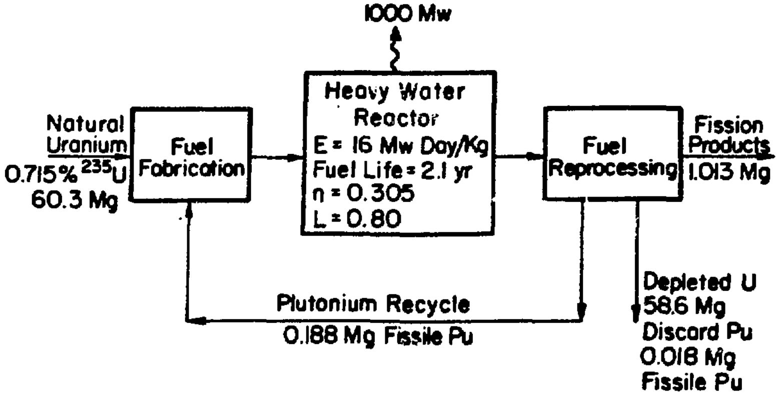

Figure 13. Annual material flow for a 1000 MW(e) CANDU with Pu recycle (from Ref. 5)

Because the plutonium supplements the fissile ^{235}U content of natural uranium, burnup and fuel life may be noted to be more than doubled for the recycle case.

The mass flows in Figures 10 through 13 are referenced to a single reactor of nominal 1000 MW(e) capacity. Typical fuel facility capacities are provided in Table I.

Table I.

Typical Fuel Cycle Facility Capacities (from Ref. 6)

Facility	Capacity, tonne/year
Underground Mine	14 U
Surface Mine	140 U
Mill	807 U
UF_6 Conversion	15,000 U
Enrichment	2,400 U
Uranium Fabrication	1,500 U
Mixed Oxide Fabrication	360 U+Pu
Spent Fuel Storage	3,500 U+Pu (Total Capacity)
Reprocessing	2,000 U+Pu

Nuclear material wastes are summarized in Table II. Generic descriptions are provided and nominal magnitudes are identified. The waste streams have been grouped into the following categories which contain nuclear material in the form of:

(1) natural and low-enriched ($\leq$ 3 wt% U^{235}) uranium only;

(2) "hot" plutonium -- intermediate- and high-level wastes containing plutonium; and

(3) "cold" plutonium -- low-level wastes with minimal fission-product content and containing plutonium.

The first category identified in Table II would require isotopic enrichment as well as chemical and physical concentration to produce material which could be used to construct a nuclear explosive. The second category would require chemical purification and fission-product separation plus chemical and physical concentration. The final category would require concentration and probably some chemical separation. As noted previously, safeguards against diversion of each waste stream must be predicated on the amount, form, and concentration of the nuclear material content.

TABLE II: NUCLEAR MATERIALS IN WASTES FROM REFERENCE FUEL* CYCLES

FACILITY	FUEL CYCLE* LWR OT	LWR R	HWR OT	HWR R	WASTE DESCRIPTION	NOMINAL WASTE PERCENTAGE**
URANIUM WASTES						
U Mining	X	X	X	X	Natural Uranium	--
U Milling	X	X	X	X	Natural Uranium	5 %
U_3O_8 to UO_2 Conversion	X	X	X	X	Natural Uranium	0.1%
U_3O_8 to UF_6 Conversion	X	X	X	X	Natural Uranium	0.1%
Enrichment	X	X			Depleted, Natural, Low Enr. ($\lesssim$3w/o) Uranium	0.1%
UF_6 to UO_2 Conversion	X	X			Low Enr. Uranium	0.5%
Nat. U Fabrication			X	X	Natural Uranium	0.5%
Low Enr. U Fabrication	X	X			Low Enr. Uranium	0.5%
HOT PLUTONIUM WASTES						
Reactor	X	X	X	X	Operating Waste (Negligible Nuc. Mat.)	--
					Spent Fuel (Once through cycles only)	100%
Spent Fuel Disposal	X		X		Facility Waste (Negligible Nuc. Mat.)	--
					Spent Fuel (~1% Pu, Fission Products)	100%
Reprocessing		X		X	Cladding Hulls and Spacers	0.3%
					Medium-Level Wastes	0.2%
					Vitrified High-Level Wastes	0.5%
COLD PLUTONIUM WASTES						
$Pu(NO_3)_4$ to PuO_2 Conversion		X		X	Process Wastes	0.5%
MOX Fabrication		X		X	Process Wastes	0.5%

*OT = Once-Through
R = Recycle

** $\frac{\text{Mass Nuclear Material in Waste}}{\text{Mass Nuclear Material in Process Output}} \times 100\%$

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #10: ELEMENTS OF NUCLEAR MATERIAL ACCOUNTING

Nuclear material accounting is a relatively straightforward concept. The functional applications are well understood, but often the basic elements of an adequate nuclear material accounting system are not in place. These elements will be identified and discussed.

After the session, participants will be able to

1. Understand the function of a strong Centralized Control System

   a. At the State level
   b. At the Facility level
   c. At the Material Balance Area level

2. Recognize the essential components of a strong Reporting System based on

   a. Transaction and Event Reports
   b. Inventory Reports
   c. Material Balance Reports

3. Appreciate the importance of having a nuclear materials management-oriented facility with

   a. Meaningful MBA's
   b. Logical key measurement points
   c. Appropriate measurement methods
   d. Effective inventory controls and procedures
   e. Supportive management

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #10: ELEMENTS OF NUCLEAR MATERIAL ACCOUNTING

SPEAKER: Ralph Lumb

President, NUSAC, Inc.
McLean, Virginia USA

Thursday, May 29, 1980
10:30 a.m.

BIOGRAPHY

See Session 6

SESSION 10: ELEMENTS OF NUCLEAR MATERIAL ACCOUNTING

Ralph F. Lumb
NUSAC

I. INTRODUCTION

The following is a detailed look at one vertical slice of a national material accounting system. That slice of the system will be traced from the top down to the bottom; that is, from the State level down to a material balance area. The importance of looking at the accounting system in this manner (that is, from the top down) cannot be emphasized too strongly. It is the only way that you can maintain control of its development and its implementation.

II. CENTRALIZED CONTROL

In Session #6, one of the mechanisms discussed for achieving a satisfactory State system was that of adequate control. At that time two major approaches were identified: centralized and decentralized. While I presented these as options and gave some justification for both, here I am going to dwell solely on centralized control, since I must confess, I believe that approach is far superior to a decentralized effort. Unless your situation is unique, I believe you will find yourself having to justify, defend, and indeed, fight to obtain all of the necessary staff and funding to support a material control and accounting system, and, in particular, the material accounting portion of the system. In such circumstances, centralization may be your only hope for achieving a satisfactory system.

A. Internal Control

Since we are starting this presentation from the top down, this is an appropriate time to introduce the need for the establishment of strong internal controls to monitor whatever system you develop. The more internal control that can be built in to a new system, the better assurance you will have, once the system is operational, that it will perform as intended. Good internal controls will probably be the least expensive factor in assuring a responsive and responsible material accounting system. In fact, once your system is operational, it would be surprising if you did not identify some changes that you wished to make in order to make the system more effective. Through the centralized control approach, you will be able to make these changes most efficiently. Furthermore, through the monitoring provided by the internal controls that should be developed in parallel, you will have evidence that the changes have been implemented properly.

B. Central Control System

With centralized controls in place, any other segment of your government can look to you for carrying out the mandates that it has determined it wishes to be followed. As government policies change or are modified, a centralized organization should respond to these changes in a relatively short time, and should identify the steps necessary for successful implementation by the government and industry. So while it will be the responsibility of other segments of the government to inform the nuclear material safeguards organization of its requirements, it will be the responsibility of the material accounting and control group to carry out the mandates and to be accountable for their successful implementation.

The establishment of a centralized material accounting system will assure a single source of materials management information at the State level for use by the government, and for presentation to the IAEA or to other governments as warranted.

Furthermore, persons in charge of the centralized material accounting system must accept responsibility for keeping other segments of the government informed regarding the adequacy of nuclear material accounting within the State.

Once the State's level of nuclear material accounting controls have been identified, the advantages of centralization can be realized. If all of the necessary experts do not reside at the State level of the system, it is possible to call in those from other levels to assist in the design. Once the design is completed, the system can be made available to all those who will be expected to use it, and its implementation can be monitored at the State level. And later, as changes appear warranted, it will be possible to make them in a rapid and responsive manner. Furthermore, it will be possible to identify facilities that are having trouble implementing the new features of the system, and to provide them specific guidance and assistance in a timely manner.

To introduce another point of realism in a centralized material accounting approach, let us consider the advantages of being able to coordinate and consolidate the nuclear material accounting budgets for the facilities within your State. Through such a centralized system, it will be possible for you to be aware of the overall picture and to defend the budget for nuclear material accounting.

With the establishment of a centralized State material accounting system, it will be possible for you to compare the reports submitted by the operating facilities. Such comparisons, based on an increased amount of data over that available at the individual facilities, should allow you to identify more rapidly any problem areas that may be developing in the field. Although the individual facilities may be involved in quite different operations, there will be certain common data points, and it will be possible for a centralized system to monitor such data points and to take advantage of the information that this monitoring will provide.

Finally, I should mention that a well-considered centralized State accounting system will serve as the focal point for the interaction of the State with the International Atomic Energy Agency. Since it is the State that is responsible for the submission of timely reports to the Agency, and for the content of these reports, it would follow that through a centralized system the State can assure itself that the content is proper. Also, if questions are raised by the Agency regarding the reports submitted to it, they can be directed to the centralized State organization; that organization can then respond appropriately to satisfy the Agency's concerns.

C. Facility System

Let us now consider the next level in the State's material accounting system: It can be stated that most of the advantages that have already been identified for a centralized accounting system at the State level will carry down to the facility level. However, the application and appearance of centralized control at the facility level may become blurred as a result of functional responsibilities and strong internal controls at the facility level.

Nevertheless, the establishment of a single point of responsbility for the implementation and operation of the nuclear material accounting system of the facility is important. In your contacts with the facilities from your position at the State level, it is essential that the individual who has the responsibility for providing information to you also has the authority to obtain it. Within the facility itself, the operating management has a day-to-day need for information to facilitate its operations, as well as longer-term needs upon which planning can be based. As accounting and operational changes occur, it is important that a single interface exists within the facility for the implementation of these changes.

This interface will be in a position, through utilization of internal control monitors, to know when it can advise its facility management and the management of the State system that its directives have been fulfilled.

Just as you will rarely have enough support at the State level, you will find that at the facility level the problems are even more urgent. The facilities typically are concerned with research, or with development, or with operations and other functional concerns. Their interests in a strong nuclear materials accounting system will be secondary in almost every case. Accordingly, centralization of control at the facility level is central to the survival of the accounting system and requires maximum utilization of both the available equipment and professional staff to fulfill its function. By centralizing its assets, the facility can control them and shift them as necessary to obtain full impact within the facility as specific problems arise. Centralized control provides the mechanism for marshalling such forces and bringing them to bear as needed, thereby allowing the facility to respond to the State level and to its own management level at a minimum cost.

D. Material Balance Area

The lowest level to which the application of centralized controls is recommended is the material balance area within a facility. While there are other definitions for a material balance area, one which may serve as a guide for evaluating your responsibilities in the near future, is the following: "A material balance area is an area within a particular plant, the material records for which are maintained in such a way that at any time during operations, a balance can be taken from the records to show the amount of material for which the area is responsible. Material balance areas are established as operational necessity indicates the need for them, and usually are based on some physical boundary delineation within the plant, or type of process or organizational lines."

From the above statement, there are clearly many options in the definition of a material balance area within a facility. The definition of material balance areas will be a responsibility of the facility management. However, it will be your responsibility to assure that the flow of control can be maintained from the State level down to whatever material balance areas are established within a plant. The centralized material balance accounting records must be responsive not only to the facility management's operational requirements, but also to management's accountability requirements. Experience has shown that these two responsibilities are not always in agreement; therefore, care must be maintained to assure the optimum cooperation and support within the material balance area.

While not specifically mentioned in the above definition of a material balance area, it will be quite apparent that in many instances the main function will be to localize inventory differences. Even though some types of facilities will not experience inventory differences, those that are dealing with materials in other than sealed sources are almost certain to. A careful analysis of material balance areas and the material movements therein will be of great assistance in having records that will be informative in the event there are inventory differences.

The use of centralized material accounting will facilitate control over movements of nuclear material in and out of a material balance area. Ideally, there would not be more than one entrance point and one exit point for material. However, as a practical maatter, there may be several of each. Also, depending on the type of material and the form and quantity, the determination of the amounts moving in and out of a material balance area may vary. By centralizing the material accounting controls, a greater assurance will be obtained that all of the transactions are recorded and reported based on the best available information.

I am sure many of you are aware that your strong interests in adequate nuclear material accounting systems will not necessarily be shared by those in the individual material balance areas. Almost without exception, the large majority of the staff in those areas will be concerned with operational problems. This is yet another reason for having centralized control at this level. The normal requirement is to identify an individual within a material balance area and assign him the responsibility for collecting and assuring the flow of the material accounting data. It may be necessary for the facility management to place such an individual within a material balance area since the normal staff may not have the capability or the interest.

Finally, by having a centralized material accounting system at the material balance area level, you will be able to fix responsibility for the day-to-day reporting and oversight of the nuclear materials consigned to that area.

E. Management Support

The importance of having a nuclear-materials-oriented management at the facility level should be emphasized. Probably none of you here today will be functioning at the facility level in the near future. Therefore, in order to assure proper implementation of your State's policy, it is important that you are aware of the facility staff which is identified to carry out your directives and that you provide them with adequate support.

The success with which the facility's nuclear material accounting staff can cope with its problems and resolve them satisfactorily will be largely dependent upon the facility management and their understanding and awareness of the importance of adequate accounting controls. It is in this area that you can be most supportive to the facility's staff since you will undoubtedly have better access to the facility management than they.

The facility staff responsible for the accounting function will be relatively isolated from their corresponding organizations in other facilities throughout the State, and, in fact, from the comparable State level organization. The materials accounting staff at the facility must normally look to that management level for its recognition, acceptance, and promotions. Therefore, it is important that they also recognize the importance of support from the State so that they will enter wholeheartedly into the effort to provide their management and the State with the best possible information that they can collect. In most facilities there will be a relatively small staff assigned the responsibility for maintaining the material accounting function. This staff may frequently lack some of the disciplines necessary to provide a complete balance across the entire material control and accounting spectrum. It will be your responsibility to maintain an awareness of the capabilities of those in the field and pursue programs to improve these capabilities as appropriate.

Without strong support of the facility accounting efforts from management any budgetary pressures exercised from the State level will almost invariably result in a cutback in the materials accounting function. This is only natural since there are many more people concerned with the operational aspects of a facility than there are people dedicated to providing the State with good accounting values and reports. You must maintain an awareness of this situation and do whatever you can to assure that facility management does not impose excessive budget constraints on material accounting and control efforts.

III. THE BASIC ELEMENTS OF A MATERIAL ACCOUNTING SYSTEM

The material accounting system must have the capability to prepare three types of reports: (1) the Transaction and Event Reports; (2) Inventory Reports; and (3) Material Balance Reports. To support these reports there must be a system of records.

A. Type of Record System

At the outset, the decision must be made regarding the form of the record-keeping system; that is, will it be based on manually maintained records or will the system be automated? Whether the system is manually kept or automated may not be important at the outset; however, to avoid problems later on, if the decision is made to go with a manually maintained record system, it should be of a type which can be converted to an automated system in the future.

When can a manual system be considered adequate? The answer to that will lie in the scope of the nuclear facilities within a State's borders. If relatively small research and development facilities, including research reactors, represent the initial activity, then a manually kept set of records will suffice.

If, at a later date, power reactors are established within a State, a manual system will probably be sufficient to accommodate those as well. Further, if as an outgrowth of the above types of facilities, it is determined to establish a waste storage facility, a manual system may still suffice. Therefore, you can be well down the road toward the utilization of nuclear energy before you have to really concern yourself with automating the records system.

The basis for assuming that a manually kept system will be sufficient lies in the probability that the number of transactions will be modest for the types of facilities identified, the inventories will be relatively static, and in most cases, the need to perform independent measurements will be limited.

So, with the assumption that you will utilize centralized accounting controls, it appears that a small staff, knowledgeable in the development of manually maintained records, will be sufficient to prepare the three types of reports thath are essential to a nuclear materials accounting system.

On the other hand, there are a number of facility types that may warrant the use of an automated material accounting system. If you propose to have conversion facilities within your State, that is, facilities that will be performing a number of chemical operations on the nuclear material, there is an implication that large quantities with many transactions would be involved and that maintaining control over the movement of these quantities would be relatively difficult through the use of manually kept records. If you intend to embark upon fuel fabrication activities, the amount of material, the various forms, and the continuous movement may be of sufficient magnitude that utilizing an automated system would probably be an advantage in achieving your nuclear control goals. The establishment of chemical reprocessing facilities or uranium enrichment facilities within your State would almost certainly dictate that your nuclear accounting system should be automated.

You should assess your State's requirements in the nuclear fuel cycle over the relatively near term, and if a manually kept set of accounting records will suffice, take advantage of this fact, and do not spend your limited resources in establishing an automated material accounting system. However, if ultimately you are going to have a large number of facilities of a given type, or one of the more complex types in combination with several smaller facilities, then the manual system should be designed for eventual automation.

You must remember that your material accounting system will benefit from automation only if the system is thoughtfully designed and carefully implemented. Otherwise, you will find that maintenance of the system will consume a major portion of the energy and attention of your material accounting personnel without a corresponding return in the information that the system will provide.

B. Type of Records

Regardless of whether the record keeping system is manual or automated, and regardless of the type of facility to which the system is applied, it basically will make little difference in the design of the system. There is both a minimum and a maximum number of records which can be maintained and, depending on the facilities in the State, the records will vary between these levels. For good accounting purposes and to allow a meaningful level of internal control, whatever the accounting system established within your State, it must be based on the double entry concept. It is not our purpose, nor do we have the time to go into the design of a double entry system. If you are not acquainted with the concept, you should seek the advice of a professional accountant.

Every system will need a general ledger in which all of the control accounts will be entered. As an adjunct to the general ledger, a general journal will be required for establishing transactions that do not fall within the regular routine of activities. In addition to the general ledger, a number of subsidiary ledgers may be necessary. These would include a receipt ledger which would reflect all receipts, a shipments ledger, an inventory ledger, and a ledger to encompass other removals. The records that I have identified so far would apply at the State level or the facility level; in addition, a material balance area ledger may be necessary at the facility level.

Each of the sets of ledgers mentioned above are applicable to a specific material type such as uranium, plutonium, thorium, and so on. Therefore, if you have two types of material, then two complete sets of the above ledgers would have to be maintained; and if you have three, three sets would be maintained. A futher refinement of this may be necessary if you have different enrichments of uranium to control; you may find it valuable to establish individual sets of ledgers for each of the enrichment levels.

If you can determine whether manually maintained records or automated records would be suitable for your State and its facilities, then you will logically be in a position to determine the extent to which the types of records just mentioned would be applicable within your State and the facilities operating within the State. It is very important that you make these determinations judiciously; often the records can be very simple depending on the types of facilities. For example, in a small research and development facility, such as might exist at a university, you might have a receipts ledger with only one page and possibly two or three entries a year. The shipments ledger may have only one entry a year and, the inventory ledger may contain only three or four different forms of material.

C. Type of Reports

Let us now consider the types of reports that will be derived from these records and that will contribute to the establishment of the State records.

1. Transaction Reports. First, there are the transaction and event reports which reflect the relevant information concerning a receipt, a shipment, production of plutonium, operational loss, etc. Because of the relatively broad external distribution of such reports, they have a high degree of visibility; therefore, care should be taken in their preparation. If a mistake is made on a document covering a shipment to another State, or a receipt from another State, it is difficult to make a correction. While the other State involved may be gracious in understanding how an error may occur, sometimes one's own management is less tolerant.

Accordingly, I wish to emphasize the care which should be taken in the preparation of transaction and event reports. They should be reviewed carefully for completeness and accuracy and it is essential that they be dispatched promptly so that all parties involved will have a timely awareness of material movement. Furthermore, these documents have a major impact on the accuracy of the material accounting values that will be maintained within a State or a facility; therefore, their preparation should not be considered a mere clerical function, but rather one involving a high level of responsibility.

The format of transaction reports and, for that matter, any type of report should be kept as functional and as simple as possible. Report design is an activity in which centralized control has an important role, especially in establishing uniformity among the facilities. We all are familiar with reports which contain requirements for more data than are necessary to accomplish the intended task. Care must be taken that the requirements for transaction reports relate to the use for which they are intended. There is relative freedom of design within a facility or within a State; however, if the transactions involve another State, then you have a responsibility to assure that there is sufficient information to meet the needs of the recipient State.

It will be helpful for those who must prepare the transaction reports and those who must rely on the data they contain if the data elements are similar at the different levels of reporting and if the general appearance of the form is similar. If possible, you should obtain counsel from the facilities regarding the data elements that they deem necessary and match those with the ones which are already identified as necessary at the State level. Then you should seek professional assistance in designing forms to incorporate all necessary information on a single document.

Classification of transaction and event reports is frequently quite subjective. While it may not be of direct concern in the design of a material accounting system, it is important that there be clearly defined classifications. The determination of whether an inventory difference can be attributed to normal operating losses, or to an accidental loss, if often a matter judgement. The accounting system records the judgement that has been made regarding the event. If, in somebody's opinion, the event has been recorded improperly, the accounting system will be closely interrogated. It will be in your best interest as systems designers and managers to assure that classifications are clearly defined, that event reporting is fully documented, and that the supporting documentation can be recalled even years after the event has taken place.

2. Inventory Reports. There are a number of considerations in establishing the criteria for inventory reporting. Possibly the most fundamental, at least at the operating level, is the frequency with which inventories must be taken and reports generated. Close behind that consideration is the matter of timeliness of reporting. I am sure that most of you are aware that independent decisions in these areas are largely a thing of the past. The International Atomic Energy Agency has expressed levels of frequency and timeliness for reports from member States. If you have not done so already, you will be establishing your own levels within your State for facilities that report to you. And finally, the facility managers will identify, from experience, the levels sufficient for adequate operational control. It is not unusual that facility managers express a need for a different frequency and faster turn around time in obtaining the results than either the State or the IAEA.

Inventory taking is quite expensive both in its economic terms and in the operational effort. The suspension of production to take inventories is something which the operational managers tend to resent and with good reason. Accordingly, I suggest that whenever possible you obtain the operating manager's support to describe the inventory in terms that are operationally meaningful. They are quite aware that they need information regarding their inventories in order to manage their plants satisfactorily. If the information they need is not included in the reports required by the State, the operators may be less than cooperative in taking and reporting inventories.

So, to the extent possible, I urge you to take the facilities into your counsel as you determine the inventory categories, the frequency with which inventories must be taken, and the timeliness with which the results must be forwarded to you. Only rarely will you find that your needs at the State level cannot be accommodated by information routinely generated for operational purposes. Furthermore, you should also be able to meet the IAEA needs by careful consideration of their criteria, compared with the operational categories that you develop.

Bear in mind that your material accounting system will be the recipient of the inventory data, and will be responsible for assembling it into reports useful to all levels of management within your State and the IAEA. Thought must be given as to how the inventory values will be determined in the first instance. Unless you are aware of how the inventory quantities are determined, you may attribute to these quantitites much more credibility than is warranted. The form and quantity of material to be inventoried will have a great influence on the frequency of required inventories and the timeliness with which the results must be reported. You must be aware of these considerations and avoid requiring an inventory procedure and reporting system that is not in keeping with the needed results.

3. Material Balance Report. The material balance reports (MBRs) are the most formal reports generated by the material accounting system. Their format is relatively simple in that the beginning inventory plus all types of receipts must equal the ending inventory plus all types of removals.

The MBR is definitely not a working document in that it may be produced only a few times a year. It will represent a summary of events and activities for the period of time covered by the report and will therefore lack extensive detail. However, you will find that its very simplicity makes it a favorite of top management at all levels of activity. Accordingly, the numerical data in the report will tend to be referred to frequently. Therefore, it is very important that these reports be carefully prepared so that their accuracy (and therefore their credibility) remains high.

There will be a material balance report prepared for each material type, and each line of the material balance report should be traceable to an account in the general ledger. In many instances, each line in the general ledger should be traceable to a subsidiary ledger. The subsidiary ledger is maintained from the detailed data received from the facilities or the material balance areas, as the case may be. Thus, the MBR represents a normal flow of data from the lowest level up to the State, and from the State to the IAEA.

IV. INVENTORY

A. Controls

The establishment of operationally meaningful MBAs is essential to the successful utilization of the control mechanisms mentioned so far. It should be recognized that they can be based on any number of factors. Within an MBA, possibly the first consideration involves spand of controls or the magnitude of operation over which one individual can maintain good accountability control. For example, it may be somewhat unrealistic to include a research laboratory and a quality assurance section within the same material balance area. The individuals in charge of these two functions would almost certainly be of different background with different interests, and it would be unlikely that either could adequately direct the activities of the other.

The most common bases for establishing an MBA are those of physical and administrative control. Another consideration for establishing MBAs is based on the facility's ability to strike a material balance for the area with acceptable limits of error.

The error associated with input, output, and inventory should be comparable. Furthermore, every attempt should be made to establish the boundaries of the MBA at points where the measurement errors are minimized.

In any event, those responsible for establishing material balance areas should maintain an open mind and flexibility regarding their choice. Many facilities are functioning today with more material balance areas than they truly need, and there are almost an equal number that could probably exercise better controls if they established more material balance than they have.

While major operational changes within a facility, or the development of better measurement capabilities for the materials within a facility, are certainly reasons for reconsidering the existing material balance areas, administrative changes or personnel changes may exercise an equal influence.

Closely allied to the establishment of material balance areas is the ability to identify logical key measurement points for materials being processed. Careful selection of such points with the provision of suitable measurement capabilities will greatly enhance the acceptability of the material accounting reports for the facility. Since these activities are primarily internal functions of a facility, they will probably only become known from your reviews of the facility's internal operation. Based on your awareness of the situation at other facilities within your State, you will be able to evaluate the key measurements and you may be in a position to provide helpful advice concerning them.

This brings us to a recognition of a very hard fact: the accounting records for a facility are totally dependent on the measurement results that establish the data. Therefore, as you review the reports from the facilities, you must remember how the amounts shown on the report were determined. Ideally, the precision and accuracy of the measurement methods should be compatible with the strategic importance and the type of the material being reported. Finally, the measurement techniques and equipment should be commensurate with the state of the art. If due consideration is given to all of these factors, then the values reported will be as good as you can expect. Nonetheless, you should use a measurement control system as part of your internal controls to assure that the measurements system is functioning properly.

Earlier I mentioned the high level of visibility of transaction reports, and it is in this area that the proper selection of measurement methods can be quite important. Not only can the application of the most suitable measurement methods minimize shipper/receiver differences, they also provide greater assurance regarding measurement values and allow one to defend them more readily than otherwise might be the case.

Ideally, a facility's inventory controls and procedures should be commensurate with the material involved. The prudent exercise of centralized controls by the State can be of material assistance in avoiding the political pressures to do too much and the operationa pressures to do too little.

Inventory control guidelines should be developed by the State in complete cooperation with the facilities who will be expected to implement them on a day-to-day basis. At the outset, establishing storage areas cannot be seriously questions by an operational manager. The need for identifying maximum amounts of material and limiting the forms of material that can be within a material balance area also cannot be questioned. With the identification and establishment of criteria such as the above, it will be possible to modify and mold the needs of individual facilities within the criteria and thereby allow the accounting system to reflect both the individual needs of a facility and the basic reporting requirements of the State itself.

B. Inventory Procedures

It must be recognized that inventory procedures will vary widely depending on the type of facility involved, the forms of material, and many other factors. When inventory data are turned over to the facility's material accounting staff, and an inventory report is subsequently prepared and forwarded to the State, and when a report is even- tually forwarded to the IAEA, each level of organization will be in possession of sets of data about which they could ask several questions. How were the numbers arrived at? Are the inventory values based on a complete physical inventory including the weighing, sampling, analyzing, and assaying of the nuclear material? Did the facility utilize a perpetual inventory system and test certain areas of the inventory? Was the inventory based on a static situation within the facility or were moving inventory methods employed? Finally, were the inventory values based upon book inventories copied from the inventory ledgers of the facility? Any one of the above approaches, or a combination of approaches, could be used to arrive at the numbers making up the inventory report. It is for this reason that the material accounting staff should participate in the development of procedures that will be used and should be fully aware of the procedures that are used for reporting inventory values.

Operationally, there is strong desire to minimize the time involved in taking the inventory. With a schedule to be met, the managers of an operating facility will be fully aware of the time lost in taking an inventory, and its impact on their scheduled deliveries. Therefore, it is highly advisable to select whatever options are most cost effective and realistic in developing the inventory within a plant.

It will be your responsibility to evaluate the decisions made at the plant level, and determine whether the results will be acceptable based on the criteria established for your State as a whole.

V. SUMMARY

You have been given much to consider, evaluate, and place in perspective regarding your own State needs. First, in your own interests and to successfully meet the responsibilities placed on you, it is important to develop the strongest State system possible. This will be necessary so that you can respond to the requirements of your own State as well as the requirements of the International Atomic Energy Agency. Second, you should assure that the accounting systems in place at the facility level are compatible with the national system. The flow of requirements and responsibilities must be from the State level down to the individual facilities, and to achieve this you must develop a strong centralized control mechanism. Finally, the records and internal reporting requirements within your State must be realistically designed and operationally workable.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #11: NUCLEAR MATERIAL CONTROL

SPEAKER: Dr. Christopher E. Olson

Sandia Laboratories
Albuquerque, New Mexico USA

Thursday, May 29, 1980
2:00 p.m.

BIOGRAPHY

Education: Ph.D., University of New Mexico, Mathematics (1971); M. A., University of Kansas, Mathematics (1965); B. A., Mathematics and History, St. Mary's University (Texas) (1963).

Present Position: Supervisor -- Safeguards Evaluation Division, Sandia Laboratories

Present Duties: Manage group of 15 persons applying systems analysis techniques to design and evaluation problems in Safeguards, especially physical protection.

Past Experience: Contributed to NRC Special Safeguards Study (1975); Course Director for International Training Course on Physical Protection of Nuclear Facilities and Materials (1978, 1979).

Session Objectives

SESSION #11: NUCLEAR MATERIAL CONTROL

This session will provide an introduction to the technical aspects of nuclear materials control. Material control technology will be discussed in terms of four types: (1) item identification, (2) seals, (3) containment and surveillance, and (4) closed-loop control systems. The role of material control in providing suitable boundary conditions for a material accountability system will be emphasized. The session will conclude with a view of the interfaces among the three components of an effective safeguards system: physical protection, material control, and material accountability.

After the session, participants will be able to

1. Identify four major categories of material control technology.

2. Describe the functions that devices of each type are intended to perform.

3. Describe the role of material control techniques in establishing boundary conditions for a material accountability system.

4. Identify the statistical parameters commonly used to describe the performance of material control systems.

5. Describe the important interfaces among physical protection, material control, and material accountability in terms of information exchange.

SESSION 11: NUCLEAR MATERIALS CONTROL IN DOMESTIC SAFEGUARDS

C. E. Olson
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I. INTRODUCTION

Together with physical protection and material accountancy, nuclear materials control (NMC) is commonly recognized as one of the three parts of a domestic safeguards system. While there is general agreement about the functions, measures, and procedures that constitute physical protection and material accountancy, the domain of nulcear materials control is not so clearly defined. For the purposes of this session, the following definition of nuclear materials control will be used:

> Nuclear materials control is the collection of measures employed to (1) control the movement of nuclear materials into and out of material access areas, (2) prevent access to nuclear materials by persons lacking proper authorization, and (3) prevent unauthorized actions involving nuclear materials from being carried out.

As a part of a domestic safeguards system, nuclear materials control rests on the authority of the national agencies in charge of nuclear matters. Although nuclear materials control may have a positive effect on the safety of operations involving nuclear material, its primary aim is to prevent malevolent actions by subnational groups or individuals. Nuclear materials control contributes toward that aim by restricting access to nuclear material and by restricting actions involving the material.

The scope of nuclear materials control is altogether different than that of containment and surveillance, even though both nuclear materials control and C&S involve concepts of control and containment. Nuclear materials control addresses only the domestic threat, while containment and surveillance is a part of international safeguards complementary with international measures of materials accounting. Certain safeguard features may be part of both the nuclear materials control and the C&S systems, but their functions are different in the two systems, a point which is later explained in more detail.

There is considerable overlap in the scope of nuclear materials control and the scope of physical protection. Several functions of materials control fall within the domain of physical protection also. These functions include the identification of personnel with authorization to enter material access areas, the detection of intrusion by unauthorized persons, delay of intruders attempting to take possession of nuclear material, as well as others. On the other hand, nuclear materials control applies only to actions directly aimed at theft or sabotage of nuclear material, while physical protection includes measures to respond to and neutralize adversaries.

Material accountancy includes many elements not shared by nuclear materials control, e.g., inventory, custody authorization, and verification, as well as materials measurement. Rather than overlap as in the case of nuclear materials control vis-a-vis physical protection, the relationship of nuclear materials control to material accountancy is one of assuring the initial or boundary conditions on which the accuracy of the material accountancy system is based.

The remainder of this session consists of three sections. The first lists the functions of nuclear materials control, describes the measures that are part of nuclear materials control and that are designed to carry out the functions, and reviews the state-of-the-art for these measures. The second section describes the parameters commonly used to characterize the performance of nuclear materials control measures. The third section deals with the interfaces of nuclear materials control with physical protection and material accountancy.

II. FUNCTIONS, FEATURES, AND TECHNOLOGY OF NUCLEAR MATERIALS CONTROL

The functions of nuclear materials control can be grouped for convenience into three categories: detection, delay or access denial, and validation.

Detection includes the discovery of anomalies in the control plans, detection of unauthorized personnel attempting to penetrate the control system through normal means of entry, and detection of intruders attempting to enter a material access area by other means. Detection also includes identifying actions by authorized personnel involving nuclear material which fall outside the range of actions which are part of the normal operation of a process, facility, or transportation activity.

Delay or access denial is the materials control function which prevents unauthorized personnel from gaining possession of nuclear material. This function encompasses the delay function of physical protection as well as process control functions which prevent access to material.

The validation function insures that actions involving nuclear materials are authorized and that material which enters or leaves a material access area is authorized and entered into the material accountancy system.

The measures or features which constitute a nuclear materials control system can be grouped according to the functions they perform. Other subdivisions can further clarify the measures of nuclear materials control: measures taken at or on a control boundary and measures taken within a control boundary; measures taken to protect against outsiders and measures taken to protect against insider adversaries; measures taken external to the operational process and measures which are integrated with the operational process.

A control boundary may be a physical boundary or it may be a point in a process at which the type of material, its containment or the alternatives for control change. For example, the boundary of a material access area is a control boundary. The boundary between fresh fuel storage in a reactor and the reactor containment is a control boundary. Material balance areas are bounded by control boundaries. Functionally, all three aspects of nuclear materials control may be represented by measures taken at a control boundary. Within a control boundary, only measures for detection and delay are normally employed.

The distinction between outsiders and insiders is an important one for nuclear materials control measures. The insider category includes not only regular employees whose duties involve access to nuclear material, but also guard forces, management personnel, inspectors, persons with access during emergency conditions (e.g., firefighters, health physics personnel), authorized visitors, vehicle drivers, and utility or maintenance personnel. Thus, not every insider is authorized to handle nuclear material, but every insider may, at times, be authorized to enter a material access area. In order to reduce the size of the insider population, it is desirable to adhere to the following design principles:

(1) The size of material access areas should be as small as is consistent with operational constraints.

(2) The activities carried out within a material access area should be limited to the extent possible to those involving nuclear materials.

(3) Routine maintenance should be scheduled, if possible, when nuclear material is not present or is not readily accessible.

(4) Physical protection measures which make entrance of guard personnel into a material access area unnecessary are preferred over techniques which require guards to enter MAAs.

Operational processes involving nuclear material routinely employ electromechanical devices to control material movement and manipulation. Nuclear materials control as a part of domestic safeguards may be implemented external to the process or may use the operational control devices (e.g., valves, cranes, etc.) to further safeguards aims.

Table I summarizes the types of nuclear materials control measures appropriate to nuclear materials control functions, subdivided according to the categories just discussed. The remainder of this section deals with the technology in use or available for implementing these measures. The technology discussion is limited to a presentation of basic results together with references to more detailed sources of technology information.

A. Detection of Nuclear Material

At facilities containing nuclear materials in forms attractive for theft, nuclear material detectors are regularly employed at all exit portals to prevent theft or diversion by insiders. Nuclear material detectors currently used for this purpose respond either to neutron or gamma radiation. The major technical considerations that must be addressed in the selection of components and procedures and the design of portals are:

(1) Ambient or background radiation environment,

(2) Spectrum of radiation emitted by the nuclear materials to be detected,

(3) Detection of shielded nuclear material,

(4) Amount of nuclear material to be detected, and

(5) Personnel throughput requirements.

Radiation backgrounds at some locations may require that portals be shielded. As with most detection processes, the detection of nuclear material at an exit portal amounts to measuring or recognizing a signal in the presence of noise. Portal shielding may enhance this process by reducing the noise.

TABLE I

SUMMARY OF MEASURES OF NUCLEAR MATERIALS CONTROL

		At a Control Boundary	Within a Control Boundary	Insider	Outsider	External to Process	Integrated With Process
Detection of . . .	Nuclear Material	NM detectors Item control		NM detectors Item control	N.A.	NM detectors Item control	Item control
	Personnel	Credential verification Personnel ID Intrusion alarms	Intrusion alarms	N.A.	Credential verification Personnel ID Intrusion alarms		N.A.
	Unauthorized actions	N.A.	Surveillance cameras Two-man rule Remote process monitoring		N.A.	N.A.	Surveillance cameras Two-man rule Remote process monitoring
Delay or Access	Intruders	Barriers	Activated barriers, obscurants Eletro-mechanical control devices	N.A.	Barriers, activated barriers, obscurants Electro-mechanical control devices		Eletromechanical control devices
	Insiders	N.A.	Electro-mechanical control devices		N.A.	N.A.	
Validation		Material movement authorization Intrusion detection Credential verification Personnel ID Seals Containers	N.A.	Material movement authorization Personnel ID Seals Containers	Intrusion detection Credential verification Personnel ID	Material movement authorization Intrusion detection Credential verification Personnel ID Seals Containers	N.A.

Table II summarizes the components of the spectrum of radiation emitted by several nuclear materials important to domestic safeguards.

If an insider attempts to escape detection while diverting nuclear material by shielding the material, he is, in effect, reducing the magnitude of the signal that nuclear material detectors are designed to recognize. To deal with this adversary approach, the nuclear materials control system relies either on a very sensitive detection technique or on detecting the shielding material itself. This latter approach occasions the use of metal detectors in exit portals.

The most direct way of increasing the sensitivity of nuclear material detection is to increase the time during which the person or package passing through the exit portal is exposed to the detectors. A given portal configuration will, thus, tend to detect small amounts of nuclear material as the time during which the person or package is held in the portal increases. This tradeoff of time for sensitivity must be addressed in portal design in order to balance the requirements cited in (4) and (5) above.

References 1 and 2 summarize the technology available for nuclear materials detection, with special emphasis on exit portal applications.

Item control includes measures taken to restrict or compartmentalize nuclear material in such a way that the material can be moved only by specific means, with the knowledge and concurrence of authorities. For example, the design of portals at a fuel fabrication facility in such a way that fuel rods cannot physically be removed by any surreptitious route amounts to an item control measure.

Depending on the nature of the item and the operation, item cotrol can sometimes be integrated with the operational process. The simplest examples involve storage of material in containers. In this process, item control has been demonstrated

TABLE II

SELECTED RADIATION SOURCE DATA FOR SOME NUCLEAR MATERIALS
(Ref. 9, 10, 11)

	Neutrons	Gamma Rays		
	n/s/g	Decay Rate(dps/g)	Energy Range keV	(δ/s-g)
^{235}U	7×10^{-4}	8.0×10^{4}	75-210	6.2×10^{4}
^{238}U	1.5×10^{-2}	1.2×10^{4}	80-770 197-451	3.3×10^{5} 1.3×10^{5}
^{239}Pu	2.2×10^{-2}	2.3×10^{9}	80-1001 700-1001	129 121
^{238}Pu	2.5×10^{3}	-	153 766	6.5×10^{6} 1.5×10^{5}
^{240}Pu	1.0×10^{3}	-	160 642	3.5×10^{4} 1.2×10^{3}

in systems which detect the movement of any item from its assigned place and compare that movement to a list of authorized transactions (References 3 & 4).

B. Detection of Personnel

Since nuclear materials control includes preventing access to material by unauthorized persons, it is necessary to insure that those persons who enter a material access area possess the proper authorization. This control process involves three stages:

(1) Recognize the entrance of persons into an MAA (intrusion detection),

(2) Verify that the credentials of persons alleged to have authorized access are authentic (credential verification), and

(3) Positively certify that the authentic credential matches with the identity of the person seeking access (personnel identification).

The first stage, intrusion detection, relies on a variety of sensors and alarm devices, employed both within a structure and exterior to it. The state-of-the-art in intrusion detection is rapidly advancing (Reference 5). In many instances, intrusion detection may be performed by personnel alone. The most efficient mix of personnel and hardware to accomplish intrusion detection depends on the availability of skilled installation and maintenance personnel for the hardware as well as the relative cost of equipment and personnel.

Intrusion detection equipment for use outside of buildings relies on a variety of physical phenomena: vibration, seismic disturbance, microwaves (bistatic or monostatic), electric field disturbance, and others. Key observations from experience with the design and implementation of exterior intrusion detection hardware include:

(1) More than one (e.g., three or even four) type of intrusion sensing device is required to provide high assurance that a variety of intrustion techniques will be detected.

(2) Use of multiple detection sensors can provide high assurance that the detection function can be accomplished over a range of environmental conditions (natural or man-made) that may prevail.

(3) Some form of rapid alarm assessment is necessary to verify that an intrustion attempt is underway or to dismiss the alarm as resulting from some other phenomenon (e.g., animal, wind, etc.).

(4) The detection capability of detection components is jointly dependent on the component design, the intrusion means to be detected, and the environmental conditions.

Detection of intrusions into closed volumes (e.g., rooms, cargo spaces, etc.) may employ the same physical phenomena as exterior intrustion detection, with the addition of magnetic door switches, infrared beams, high frequency sound, and closed circuit television (CCTV) motion detecting devices. The relatively smaller variations of interior environmental conditions as compared to those outside make the technical solution of interior intrusion detection somewhat easier to achieve. At the same time, the requirements that sensors be matched with prevailing conditions and expected intrusion actions and that rapid alarm assessment be provided are also important for interior intrusion alarm systems.

Credential verification is accomplished at many nuclear facilities by visual examination of a badge, which usually bears a unique pattern of some sort. The procedure of comparing a badge presented by the bearer with an independent access list is a routine backup for this type of credential check. At some facilities, extensions of this badge system are used for the purpose of complicating possible attempts to forge credentials. These extensions include:

(1) Addition of a magnetic strip to the badge and coding a unique credential "message" on the strip which can be read by entry control devices to a master file.

(2) Exchange of the badge presented by the bearer at an access control point for a badge which remains in the custody of the safeguards system when the person leaves the materials access area.

(3) Use of a timed-loop or magnetically coded badge together with readers or sensors which automatically compare the badge passing through an access control point to a master file of authorized credentials.

Personnel identification is an active area of current research and development. The approach used in developing hardware is to identify and measure some physiological parameter unique to each individual. A data base of measurements for all persons with authorized access would be maintained and the appropriate data recalled and compared to measurements made when a person presents himself at an access control point. Personnel identification devices are currently available which measure: fingerprint parameters, voice characteristics, hand geometry, and written signature. These techniques can be, by themselves, effective in rejecting unauthorized persons. Their effectiveness can be further increased by associating with the physiological measurement such additional authentication parameters as passwords, remembered access codes, and the comparison of a photograph or stored image with the face of the person seeking access. Extensive test and development data on the performance of personnel identification equipment are contained in Ref. 1.

C. Detection of Unauthorized Actions

This material control function involves monitoring or surveillance of personnel with authorized access to insure that no unauthorized actions take place involving nuclear material. There are a number of measures (both hardware and procedural) that facilitate the detection of unauthorized actions.

In the first place, facility and/or vehicle layouts or process lines which assist in clarifying the distinction between authorized and unauthorized actions will, in general, assist in the development of practical detection measures. This principle tends to favor:

(1) Automation of processing and movement--so that handling device position readouts can be used to record and signal movement of material outside normal bounds;

(2) Limited number of material access points--to reduce the surveillance burden;

(3) Specialization of equipment and tasks--so that authorized activities can be sharply defined according to the tools and the personnel involved.

Some unauthorized actions may lead to emergency conditions such as fire or criticality for which detection is normally considered to be a safety function. In that such conditions may either indicate an anomaly in the material control system or an impending situation where the material control system may not function as intended, it is useful to relay emergency alarms to the responsible safeguards personnel in time for assessment and preventive action to take place. This requirement is one important interface between safeguards and safety.

One procedure often used to detect unauthorized action is the two-man rule. This procedure requires that persons be allowed into a material access area only if accompanied by at least one other individual who is well-acquainted with the actions authorized. Adherence to this procedure can be enforced by a variety of means, e.g., comparison of process records with access records, guard surveillance at access portals, exchange badges, etc. In effect, entry by a lone person into the material access area becomes an easily recognizable unauthorized action.

Another means of detecting unauthorized actions is by CCTV surveillance. As originally conceived, this approach extends the two-man rule concept by pairing a knowledgeable person in a remote location with persons in a material access area. However, new technical developments have made automatic alarm generation via CCTV possible for certain types of action. Simply put, portions of the CCTV screen pattern generated from a fixed camera can be designated as alarm regions; any activity or movement within these regions causes an alarm and may be recorded for later viewing. Reference 5 contains data on CCTV equipment. Mastering the technical problems of field-of-view, glare, contrast, and reliability in a practical installation is the subject of a rapidly expanding body of experience reported in Ref. 5.

Other methods of remotely monitoring the actions of authorized personnel exist. For example, process line measurements (weights, radiation, etc.) can be relayed to a remote control point and compared to predetermined standards. This technique, while possibly employing some instrumentation similar to that used in material accountancy, is different from MA practices in that its purpose is to detect anomalies in a well-defined operational procedure rather than to refine or update material balance accounts.

The usefulness of any technological assistance in detecting unauthorized actions depends ultimately on human skill at recognizing the distinctions between what is authorized and what is not. In the case of some nuclear operations, this requirement is still poorly understood and is the subject of extensive current research. Nowhere is the difficulty more easily demonstrated than in the case of power reactors.

D. Delay of Intruders

Once the nuclear materials control system has detected an unauthorized penetration of a material access area (or its surrounding protected area), it may be necessary to impose a delay on the intruder of sufficient duration to allow elements of the physical protection system to be brought to bear. Delay in this context can be thought of as a form of access denial which facilitates the maintenance of nuclear material control by the designated authority. There are several types of nuclear materials control measures which may assist in achieving the required delay or access denial: passive barriers, activated barriers, and obscurants.

Passive barriers include walls, fences and gratings, vaults, locking mechanisms, tiedowns, and some containers. They are always in place, and their continuing integrity also serves the nuclear materials control function of validation as described later in this session. The extent of the delay which can be imposed by a given configuration of passive barriers deployed around and within a material access area has been the subject of extensive research and testing, as reported in Ref. 6. One conclusion reached in this work is that very long delay (say, tens of minutes) or absolute access denial may be expensive and extremely difficult to achieve with passive barriers against a well-prepared adversary.

Activated barriers include both rigid and sticky foams, deployable bulk barriers like rubble or earth, and remotely controlled doors which can be closed rapidly if necessary. Because of the difficulty of penetrating them, the foams offer a unique possibility for long delay when deployed in an emergency in closed volumes through which access by authorized personnel is normally required. Applications could include hallways, vaults, entry rooms, or vehicle cargo space. Foams present some safety questions which have not been completely resolved at this time. Further information is available in Ref. 7.

The concept of obscurants is to maintain control of nuclear materials by making the complex adversary task of penetrating a material access area and seizing material more complicated by denying visual access to the adversary. Perhaps the best example of an obscurant is smoke. Obscurants appear to be most effective when used in combination with passive or active barriers. Again, Ref. 7 provides more extensive details.

E. Delay of Unauthorized Actions

For this nuclear materials control function, there is no question of denying access; the adversary who must be delayed already enjoys access for the purpose of carrying out legitimate operational activities. Of the delay measures already cited, only the activated barriers are likely to be applicable, even in limited ways.

However, another means of delaying unauthorized actions involving nuclear materials is possible for some operations. This measure consists of interrupting power or otherwise disengaging electromechanical devices which are required for the movement or manipulation of the material. A number of examples come to mind: interrupting electrical power or pressure to valve actuators, cutting power to cranes or handling devices, shutting off or disabling vehicle engines, etc. These actions may be taken in response to detection of an attempt to carry out unauthorized material actions or they may be taken routinely at times when no authorized material actions are scheduled. The success of these measures depends on the uniqueness of the electromechanical device in carrying out the action to be prevented. Nuclear material control can thus be enhanced if the movement or manipulation of the nuclear material requires the application of devices subject to the control of designated authorities. Figure 1 illustrates an application of this concept. In the figure, the crane is essential for removing nuclear material containers from the truck or from storage. By cutting power to or disabling the crane, access to material in the truck or in the vault is effectively denied.

F. Validation

In order to assure the accuracy of material balance accounts, it is necessary to insure that nuclear material enters and leaves material access areas only through authorized channels and that material within the access area remains within the cognizance of the material accountancy system. Furthermore, if material unaccounted for exceeds prescribed standards, it is necessary to ascertain the chances that it could have been diverted, stolen, or otherwise misused. Meeting these requirements is a function of the nuclear materials control system that is referred to as validation. The term validation can be thought of as a shortened form of validation of the assumptions

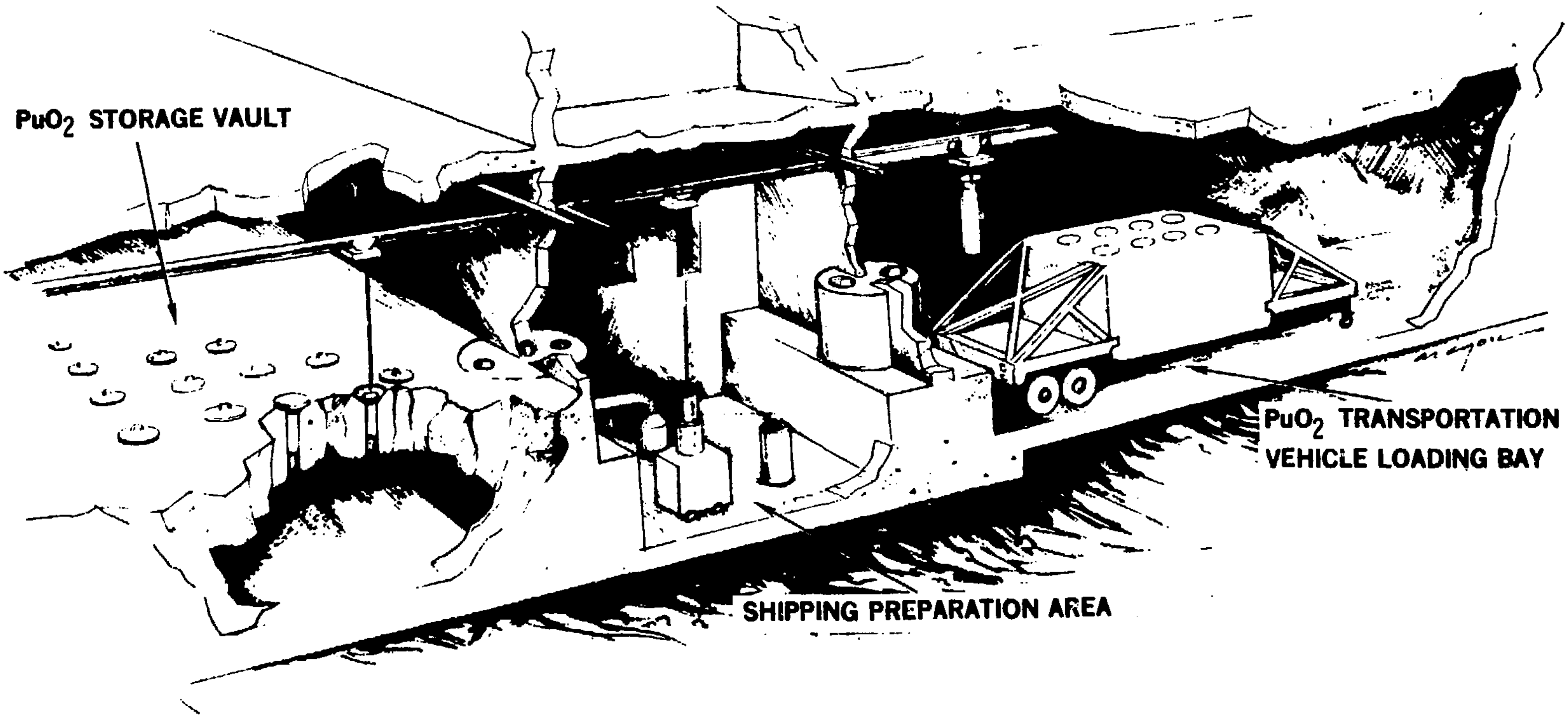

Figure 1. Example of Opportunities for Electromechanical Device Interruption

or boundary conditions on which material accountancy is based. As noted in Table I, many measured which carry out other nuclear materials control functions are also applicable to validation. For example, intrusion detection systems not only provide an alarm if a penetration occurs, they also serve to assure that no penetration has occurred during a given material accountancy period or cycle. It is thus not only the one-time detection capability but also the cumulative assurance provided by an absence of alarms that characterizes the overall contribution of intrusion detection measures to nuclear materials controls in domestic safeguards.

The integrity of the barriers which forces the movement of material to pass through monitored channels is evidently another factor in the validation function. In the case of structural barriers, integrity is readily verified. But for barriers such as locks, doors, and containers, verification of integrity is assisted by the use of seals. In this context, the function of the seal is to provide a positive indication that no surreptitious penetration of the barrier has occurred. This role is distinct from detection in that negative indication (i.e., the seal is broken and penetration has occurred) is unlikely to be timely and distinct from delay in that such seals can be broken easily and quickly. In the validation role, seals and containers function together to permit item control and measurement which may streamline some portions of the material accountancy process (e.g., as in Ref. 3). A comprehensive survey of seal technology is available in Ref. 8.

III. NUCLEAR MATERIALS CONTROL PERFORMANCE PARAMETERS

There is no single index or parameter that conveys the performance of a whole nuclear materials control system. Just as nuclear materials control is an amalgam of several functions, so the performance of the nuclear materials control system as a whole can best be examined by considering a collection of parameters describing how well each function is carried out. Since the domestic safeguards environment is to a degree two-sided (adversaries versus designated authority), it is not surprising that in the final analysis, nuclear materials control performance depends in part on the nature of the potential adversary. For example, a particular set of nuclear materials control measures at a nuclear facility might be determined to be highly effective in insuring that insiders could not surreptitiously misuse nuclear material present at the facility, but the same measures might offer little resistance to force applied by a determined outside group.

The detection functions of nuclear materials control measures are most readily characterized by probability of detection, P_d, and false alarm rate, FAR. P_d must be thought of as depending not only on the characteristics of the sensor itself, but also on the actions or objects it is meant to detect. FAR includes nuisance alarms generated by actions or objects which pose no threat to material control as well as alarms produced by equipment malfunction or noise. Evidently, FAR is dependent on the detection equipment design, the installation, maintenance, and operating procedures in use, and the man-made and natural environment in which the detection equipment is operated. The overall detection function can be thought of as the cumulative P_d integrated over all adversary actions and characteristics which are meant to be detected.

The delay function performance of nuclear materials control measures is described by delay time after detection. The importance of achieving a given delay time depends naturally on related parameters for physical protection system functions. In other words, the usefulness of delay as a part of nuclear materials control depends in part on the response time of the physical protection system. Once again, the range of characteristics of the adversary considered will influence the delay time which a given measure can achieve. Nuclear materials control system delay is also adversary dependent and consists of the minimum cumulative delay imposed on the adversary by the collection of delay measures in place.

The validation function of a nuclear materials control measure can be expressed in terms opposite to those used for detection. Whereas detection was represented as P_d, validation is expressed by the probability that the absence over time of any observed control anomaly (e.g., penetration, diversion, etc.) represents the true state of affairs. In other words, validation is expressed as a confidence in a null hypothesis. Once again, dependence on the characteristics of a potential adversary is evident. It can be seen that shortening the material accountancy time cycle increases validation confidence, if other parameters are held constant. Similarly, a uniform increase in P_d's for all relevant detection functions also increases validation confidence.

IV. THE RELATIONSHIP OF NUCLEAR MATERIALS CONTROL TO MATERIAL ACCOUNTANCY AND PHYSICAL PROTECTION

The relationship of nuclear materials control to material accountancy and physical protection has already been alluded to in the context of the functions and measures of these three components of domestic safeguards. This section summarizes those observations in terms of the information upon which each safegaurds subsystem is based.

There is considerable overlap between measures employed for nuclear materials control for detection and access denial and those used for detection and delay in physical protection. Indeed, in many instances, the same device or procedure can properly be considered a part of both nuclear materials control and physical protection. The difference in the use which nuclear materials control and physical protection make of the same detection information illustrates the nature of this interface. In physical protection, detection information that indicates the presence of an intruder or unauthorized person generates an alarm and a response by the protective force. It may also key the deployment of active barriers, an application shared with nuclear materials control. In nuclear materials control, however, the primary use of detection information is to create a time-history of personnel access to material access areas in order to verify that the control of sensitive material has remained in the hands of designated authority. It is not the function of nuclear materials control to launch a protective force response or to arrest or neutralize intruders. Deployment of active barriers and interruption of power to electromechanical devices falls within the purview of nuclear materials control since both techniques can apply to maintaining control of access to the material.

The interface between nuclear materials control and material accountancy is mediated by the validation function of the nuclear materials control system. In effect, the nuclear materials control system supplies boundary condition status information to the material accountancy system to assure that:

(1) The material measured and inventoried includes all material authorized to be present in a material balance area;

(2) The persons performing the measurements are authorized to do so;

(3) The persons with access to the material are authorized and their actions are in conformance with approved tasks.

The practical matter of designing, implementing and operating a domestic safeguards system in which nuclear materials control, material accountancy, and physical protection are efficiently integrated and balanced is an areas of current research. Joint projects at Sandia and Los Alamos specifically address the question of how material accountancy and physical protection can best be integrated; the inclusion of nuclear materials control considerations in this work is unavoidable because of the close relationship of nuclear materials control to both MA and physical protection.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #12: SURVEY OF STATISTICAL METHODS IN NUCLEAR MATERIAL ACCOUNTING AND CONTROL

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Thursday, May 29, 1980
4:00 p.m.

BIOGRAPHY

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Author of book "Statistical Methods in Nuclear Materials Control."

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #12: SURVEY OF STATISTICAL METHODS IN NUCLEAR MATERIAL ACCOUNTING AND CONTROL

Inferences are made about facility SNM control performance based on facility material balance data that produce a value for MUF (material unaccounted for), and also based on measurements made by a second party. This second party may be either the shipper or the receiver in the case of material transfers, or the inspector in an inspection situation. Statistical methods play an important role in making these inferences because of errors of measurement associated with measuring nuclear materials. This session considers the sources and types of measurement errors and their effects in drawing conclusions about facility material control performance based on the performance measures in question.

After the session, participants will be able to

1. Identify the sources of measurement errors pertinent to safeguards for typical facilities.

2. Characterize the types of measurement errors as they affect the uncertainties of safeguards indices.

3. Calculate the variance of any arbitrary function of random variables.

4. Calculate the variance for a facility MUF, given the required input information.

5. Calculate the variance for a difference statistic, either a shipper/receiver difference or a facility/inspector difference.

6. Explain the role of statistics in making inferences based on inspection data.

SESSION 12: SURVEY OF STATISTICAL METHODS IN NUCLEAR MATERIAL ACCOUNTING AND CONTROL

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Exxon Nuclear Company

I. INTRODUCTION

Measurements are essential to a nuclear materials accounting system. For example, when material is transferred from one responsible custodian to another, it is usually measured; when material is inventoried, it is often measured; and when an audit inspection is performed, measurements are made.

If a measured value were always equal to the true value of the item being measured, there would be little need for a statistical treatment. This is not to say that the problems associated with the accounting of nuclear materials would disappear, because decisions would still be required, for example, on the part of management or a regulating agency, as to how much "true" material unaccounted for (MUF) is tolerable in a given situation. However, against a backdrop of uncertainties due to measurement, these problems are greatly multiplied. This is especially true in accounting for nuclear materials because the measurement problems are not trivial; the "noise level" is moderately high in a relative sense.

Statistical inference in nuclear materials accounting is centered on the concept of a statistical "error" associated with a measured value, i.e., a measurement error. An error of measurement can be defined as the magnitude of the sign of the difference between a measured value and the corresponding true value. It is important to distinguish between an error and a mistake. A measurement <u>error</u> is committed because of limitations of the measurement system. A <u>mistake</u> is made when the operator of the system either does not use the system properly in a given instance or does not record properly the value produced by the system (e.g., he transposes numbers).

It may be difficult to factor the effects of mistakes into an analysis because of their unpredictability, with respect to both size and frequency. Some steps can be taken in this regard, however, and this topic is considered briefly in Section VI. It is possible, however, to deal quite completely with errors of measurement, measurement being used in its broadest meaning to include all sources of error that might affect the quality of a final measured value.

A given observation will, in general, be affected by several individual errors, each drawn from a different population. Some of these error sources are identified; others may not be. The effects of some can be combined and described by one broad error source. In modeling to account for the various error sources that might affect the value of an observation, ideally one tries to identify and evaluate the effects of all these sources individually. However, the ideal goal is, for the most part, a physical impossibility. Rather, error sources are grouped and the principal error sources identified, where an error source is classified as principal either because of the magnitude of the expected error or because of the importance of the operation involved, or for both reasons. Thus the error introduced by the weighing operation, for example, although it may not have a great effect on the size of the total error, is generally included in the analysis because of the significance of the weighing operation in nuclear materials control measurements. In Section II, the principal error sources generally identified in nuclear materials accountability are discussed.

In evaluating the effects of errors of measurement, it is essential to have in mind an explicit mathematical model for each identified error. Errors are modeled differently: some may be completely random in their behavior; others may affect results as a bias or a systematic error; still other errors are neither completely random nor systematic, but somewhere in-between. Furthermore, some errors may affect measurements comparably on an absolute basis, and others on a relative or percentage basis. Errors may not be independent of one another. A mathematical model is a complete specification of these error characteristics. Modeling of measurement errors is discussed in Section III.

Having identified the error sources and modeled each error, the next step is to determine the net effect of all errors as they affect a given performance index, such as a facility MUF*, a shipper-receiver difference, or a difference between a facility and an inspection assessment of total inventory, say. The process by which this net effect of several errors is determined is called error propagation. General error propagation formulas are given and exemplified in Section IV. These form the basis for error propagation procedures that may be used to calculate the variance of a facility MUF and/or a difference statistic as given in Section V. Of particular interest in the context of IAEA inspections is the difference statistic that is derived from a comparison of facility and inspection results. A brief discussion of how such inspection data may be evaluated is contained in Section VI.

II. SOURCES OF MEASUREMENT ERRORS

There are many error sources which can conceivably affect an observed value. Clearly, it is a physical impossibility to identify and account for all potential error sources in routine analyses of data, nor is this necessary. This does not imply that the contributions from some error sources are ignored but rather that they are combined with others to result in principal error sources.

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*The term "MUF" (Material Unaccounted For) is being replaced in the U.S. by the term "I.D." (Inventory Difference). It is recognized that "MUF" is the terminology currently being used by the IAEA.

To emphasize this point, consider a measurement situation in which the total uranium in a process tank is to be determined by measuring the volume in the tank with a dip-tube manometer system and then measuring the concentration for a sample drawn from the tank. In calculating the total amount of uranium in this fashion several sources of measurement error may be identified. These might include those sources listed below.

- Reading the manometer
- Measuring the specific gravity
- Distinguishing the titration end point
- Pipetting the sample
- Reading the buret liquid level
- Sampling the solution (due to imperfect mixing)
- Sampling the solution (due to presence of solids)
- Uncertainty in volume calibration curve
- Normality of titration
- Pipet calibration
- Buret calibration
- Titratable impurities in sample
- Persistent temperature effects on manometer fluid
- Specific gravity changes in manometer fluid

With so many sources affecting a single measurement and with so many measurements affecting quantities of interest in the accountability of nuclear materials, such as MUF, it is evident that a balance must be struck between the amount of detail that can be identified and included in an analysis and what is practical.

The amount of detail that should be included depends upon the motivation for the analysis. If a study of measurement systems is being made to identify and evaluate many error sources, considerable detail will obviously be required. On the other hand, if the problem is one of testing for the significance of a given MUF, the analysis will be less detailed.

The major interest in this discussion centers on the latter type of application. Therefore there is a limit on the amount of detailed error analysis that need be performed. The amount of detail used in subsequent sections is described in the following paragraph.

Five basic types of measurement operations are identified: weighing, volume determination, sampling, analysis, and nondestructive assay (NDA). The sampling and analysis operations are defined separately with respect to the element (uranium or plutonium) and the isotope (U-235 or fissile plutonium). Associated with each measurement operation is a "method." For the weighing operation, the method refers to the scale or balance used; for volume determination, it refers to a given dip-tube manometer system or some other system used to measure volume; for sampling, it indicates the type of material being sampled in combination with the equipment and technique used to draw the sample; for analysis, it is the analytical equipment and technique used; and for an NDA measurement, the method is identified with the equipment and technique used.

In effect this procedure combines the effects of all errors associated with a given operation--method combination into one error. This does not limit the scope of the analysis, because it is permissible to combine the effects of the errors in this fashion.

III. TYPES OF MEASUREMENT ERRORS

The importance of modeling measurement errors was pointed out in the Introduction. It may not always be necessary to write the model explicitly, but the form of the model must be kept in mind. Basic to the model is a recognition of the different types of measurement errors that may affect a result.

There are three broad categories or types of errors that will be identified. These are random errors, systematic errors or biases, and errors that fall in neither category, which may be called short-term systematic errors. The different kinds of errors are perhaps best understood in the context of an example.

A. Random Errors

The example is as follows. Six sintered UO_2 pellets of nominally the same composition are to be analyzed for percent uranium. Let

x_i = measured percent uranium for pellet i

μ = nominal (or true) percent uranium

p_i = deviation from the nominal value for pellet i

ε_j = deviation due to analytical for measurement j

For simplicity, an additive model is assumed. The model representing the six measured values may be written:

$$x_1 = \mu + p_1 + \varepsilon_1$$
$$x_2 = \mu + p_2 + \varepsilon_2$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$x_6 = \mu + p_6 + \varepsilon_6 \; .$$

Consider p_i. Since this differs from each of the six observations in the data set, p_i is called a random error. If p_i may be regarded as a random variable with zero mean and with variance σ_p^2, then σ_p^2 is called a random error variance due to sampling. Note the important distinction between p_i and σ_p^2; p_i is an error while σ_p^2 is an error variance.

Consider ε_j. Since this also differs for each of the observations in the data set, ε_j is also a random error. More specifically, ε_j is an analytical random error and, analogous with σ_p^2, the quantity σ_ε^2 is called the random error variance due to analytical.

It is noted that since p and ε have the same subscripts for all six observations, it is not possible to distinguish between the sampling and analytical errors. One might wish to combine them in the model, replacing $(p_1+\varepsilon_1)$ by m_1, etc. The quantity m_1

might then be called the measurement random error, and σ_m^2 the measurement random error variance.

The characteristic feature of a random error in a model is that its subscript changes for each observation in the data set. The safeguards significance of random errors is that their effect on measurement uncertainty can be reduced by making additional measurements. For this reason, random errors are controllable and, given sufficient resources, can be made to have little importance in many safeguards applications.

B. Systematic Errors; Biases

The model is extended. Let

Δ = deviation from the nominal due to the analytical method, for all measurements in the data set.

Then write

$$x_1 = \mu + \Delta + p_1 + \varepsilon_1$$
$$x_2 = \mu + \Delta + p_2 + \varepsilon_2$$
$$\vdots$$
$$x_6 = \mu + \Delta + p_6 + \varepsilon_6 \ .$$

Note that Δ differs from p_i and ε_j in that there is no subscript (or, equivalently, the subscript may be the same for all members of the data set). The quantity Δ is called a systematic error or a bias, terms which are often used interchangeably. Some users make a distinction between these two terms in the situation where the quantity Δ is estimated in some way. If observations in the data set are corrected on the basis of the estimate of Δ, then Δ is called a bias. However, since one cannot know Δ precisely, but can only estimate it, it is clear that the observations cannot be completely corrected for the bias Δ. There is a residual bias, consisting of the difference between Δ and its estimate, and this residual bias is then called the systematic error. This distinction between bias and systematic error is not made by all modelers. The important idea to keep in mind is that whatever the Δ quantity is called, the assumptions concerning Δ must be stated or implied so that errors can be properly propagated corresponding to the assumed model.

The distinction between the systematic error and the random error is that the subscript on the systematic error is the same for all members of the data set (or, equivalently, there is no subscript). If Δ is a random variable with zero mean and variance $\sigma_\Delta{}^2$, then $\sigma_\Delta{}^2$ is called a systematic error variance.

In many safeguards applications, the effect of the systematic error is of dominant importance when compared with that of the random error. This is because, unlike the random error, the effect of the systematic error cannot be reduced by taking additional measurements. The systematic error limits the effectiveness of safeguards from the material accounting point of view, unless steps can be taken to reduce its effect in some way. Merely making more measurements will not help.

C. Short-Term Systematic Errors

The model is further extended. Suppose that the six pellets are not all distributed to the same laboratory for analysis. Let

l_k = deviation from the nominal due to the analysis being performed in laboratory k

Also suppose that within laboratory k, conditions change from one time-frame (day, shift, week, etc.) to the next so that

$t_{m(k)}$ = deviation from the nominal due to the analysis being performed in time frame m within laboratory k

Note that in the case of $t_{m(k)}$, the subscript is written to indicate that the "time" effect is peculiar to a given laboratory. That is, time from 1 in laboratory 1 does not correspond to time frame 1 in laboratory 2, say.

With l_k and $t_{m(k)}$ defined, suppose that the model now becomes

$$x_1 = \mu + \Delta + l_1 + t_{1(1)} + p_1 + \varepsilon_1$$

$$x_2 = \mu + \Delta + l_1 + t_{1(1)} + p_2 + \varepsilon_2$$

$$x_3 = \mu + \Delta + l_1 + t_{1(1)} + p_3 + \varepsilon_3$$
$$x_4 = \mu + \Delta + l_2 + t_{1(2)} + p_4 + \varepsilon_4$$
$$x_5 = \mu + \Delta + l_2 + t_{2(2)} + p_5 + \varepsilon_5$$
$$x_6 = \mu + W + l_2 + t_{3(2)} + p_6 + \varepsilon_6 .$$

The model indicates that three of the pellets were sent to one laboratory where all three analyses were performed in the same time frame, and three were sent to a second laboratory where one analysis was performed in each of three time frames. Both laboratories used the same analytical technique and the random error variances due to analytical are assumed to be identical (indicated by use of ε_j for all six measurements).

The quantities l_k and $t_{m(k)}$ differ from both the random error (p_i and ε_j) and the systematic error (Δ) in that for each error, the subscript is the same for some members of the data set, but not for all. Thus, l_k and $t_{m(k)}$ are neither random nor systematic errors, but are some kind of intermediate type error.

In this particular application, l_k may be called a laboratory error or effect, and $t_{m(k)}$ may be called a time effect, or a laboratory condition effect. In more general terminology, this type of error that is intermediate to a random and a systematic error has been commonly referred to as a short-term systematic error in safeguards applications. In making a distinction between this and the systematic error of Section III.B, the latter is sometimes called a long-term systematic error.

It should be noted here that the distinction that is made between random errors, systematic errors, and short-term systematic errors is with respect to the particular set of data under discussion. For example, if the data set were to consist of only the first three observations rather than all six, then l_k and $t_{m(k)}$ would both be (long-term) systematic errors rather than short-term systematic errors, for then the subscript would be the same for all members of the data set.

IV. ERROR PROPAGATION

Error propagation refers to the process in which the net effect of all errors affecting a given reported result is developed. When propagating errors, it is essential to have in mind a mathematical model that relates the random variable of interest to other variables or factors. Error propagation is really nothing more than a mathematical exercise so that, given a model, there can be only one correctly propagated error, assuming that a given approximation formula is used. Hence, the importance of the model.

No mathematical model will ever provide a perfect description of reality, except perhaps in very simple cases. The aim in writing a model is to obtain a good approximation to reality. At the same time, the model should be sufficiently simple to permit error propagation without introducing undue complexities. A proper balance between these two objectives is essential.

The additive or linear model is the simplest one with which to work, and is often a suitable approximation to reality. However, in many safeguards applications, measurement errors are expressed on a relative basis; this calls for the use of a multiplicative model. Further, the amount of uranium or U-235, or of plutonium, is often determined by multiplying net weights or volumes by concentration. The model describing this process is clearly non-linear.

In developing error propagation formulas, an important result for the linear model is first developed. This is then applied to a non-linear model by approximating the non-linear model by a linear one through expansion of the function around the means of the random variables using the linear terms of a Taylor's series expansion. The specifics are as follows: For a linear model, if

$$x = a_1x_1 + a_2x_2 + \dots + a_kx_k$$

where the a_i are constants, where x_1, x_2, ..., x_k are random variables with means μ_1, μ_2, ..., μ_k and variances $\sigma_1{}^2$, $\sigma_2{}^2$, ..., $\sigma_k{}^2$, and with the covariance between x_i and x_j being σ_{ij}, then the mean and variance of x, denoted by μ and σ^2 respectively, are

$$\mu = a_1\mu_2 + a_2\mu_2 + \ldots + a_{kx}\mu_k$$

and

$$\sigma^2 = a_1{}^2\sigma_1{}^2 + a_2{}^2\sigma_2{}^2 + \ldots + a_k{}^2\sigma_k{}^2$$
$$+ 2a_1a_2\sigma_{12} + 2a_1a_3\sigma_{13} + \ldots + \ldots 2a_{k-1}a_k\sigma_{k-1,k} \; .$$

There are k(k-1)/2 covariance terms, some or all of which may be zero. Suppose that the model is now non-linear, written symbolically as

$$x = \phi(x_1, x_2, \ldots, x_k)$$

This function may be approximated by

$$x \approx \phi\,(\mu_1, \mu_2, \ldots, \mu_k) + \frac{\partial\phi}{\partial x_1}(x_1-\mu_1) + \frac{\partial\phi}{\partial x_2}(x_2-\mu_2) + \ldots$$
$$+ \frac{\partial\phi}{\partial x_k}(x_k-\mu_k) \; .$$

This is now linear in form and so the equations for the linear model may be applied. The quantity $\phi(\mu_1, \mu_2, \ldots, \mu_k)$ is, of course, a constant and does not affect the variance of x. The partial derivatives, all evaluated at μ_i for all i, are all constants, and represent the a_i constants of the linear model. Thus, assuming that the linear terms of the Taylor's series approximation is valid, as is usually the case in safeguards applications, the approximation to the variance of x is

$$\sigma^2 \approx \sum_{i=1}^{k}\left(\frac{\partial\phi}{\partial x_i}\right)^2 \sigma_i{}^2 + 2\sum_{i=1}^{k-1}\sum_{j>i}\frac{\partial\phi}{\partial x_i}\,\frac{\partial\phi}{\partial x_j}\,\sigma_{ij} \; .$$

As an example, consider the variance of the amount of U-235 in a container of UO_2 powder. Calling the measured amount x, this is computed from the equation

$$x = w\ u\ v$$

where w = net weight of UO_2 powder
u = measured uranium to UO_2 ratio
v = measured U-235 to uranium ratio

Assume that w is a random variable with mean W and variance σ_w^2; u is a random variable with mean U and variance σ_u^2; and v is a random variable wih mean V and variance σ_v^2. Further assume that the random variables are independently distributed and have zero covariance.

The required partial derivatives, evaluated at the means of the random variables, are

$$\frac{\partial x}{\partial w} = UV \quad , \quad \frac{\partial x}{\partial u} = WV \quad , \quad \frac{\partial x}{\partial v} = WU \ .$$

Thus,

$$\sigma_x^2 = (UV)^2\ \sigma_w^2 + (WV)^2\ \sigma_u^2 + (WU)^2 \sigma_v^2 \ .$$

Of course, the true mean values W, U, and V are not known. In calculating σ_x^2, they will be replaced by w, u, and v respectively.

Suppose the following data are given:

$$w = 20 \text{ kg} \qquad u = 0.876 \qquad v = 0.0425$$

$$\sigma_w = 0.05 \qquad \sigma_u = 0.001 \qquad \sigma_v = 0.0002$$

Then, $x = 0.7446$ kg U-235

and $\sigma_x^2 = 10^{-6}\ (3.4652 + 0.7225 + 12.2780) = 16.4657 \times 10^{-6}\ \text{kg}^2$ U-235

and $\sigma_x = 0.00406$ kg U-235, or 4.06 grams.

This particular example also illustrates error propagation when errors are expressed on a relative basis rather than on an absolute basis as is often the case in nuclear materials safeguards. Note that the formula for the variance of x may be written in an equivalent form:

$$\frac{\sigma_x^2}{(WUV)^2} = \frac{\sigma_w^2}{W^2} + \frac{\sigma_u^2}{U^2} + \frac{\sigma_v^2}{V^2}$$

or

$$\frac{\sigma_x}{X} = \sqrt{\frac{\sigma_w}{W}^2 + \frac{\sigma_u}{U}^2 + \frac{\sigma_v}{V}^2} \ .$$

Hence, on a relative basis, with the respective relative errors being

$$\frac{\sigma_w}{W} = 0.0025 \text{ (or } 0.25\%) \quad \frac{\sigma_u}{U} = 0.001142 \quad \frac{\sigma_v}{V} = 0.004706$$

then

$$\frac{\sigma_x}{X} = 0.00545, \quad \text{or } 0.545\% \ .$$

In the general error propagation rules to follow, it is assumed that the various measurement errors are expressed on a relative basis.

V. PROCEDURES FOR CALCULATING VARIANCES OF IMPORTANT SAFEGUARDS INDICES

In A, the variance of a facility MUF is considered. In B, the variance of a difference statistic is treated.

A. Variances of Facility MUF

The MUF for a material balance period is given symbolically by the formula:

$$MUF = I - O + BI - IE$$

where

I = Inputs
O = Outputs
BI = Beginning Inventory
EI = Ending Inventory.

Each term may represent symbolically the net effect of a large number of measurements. Each measurement, in turn, may reflect several measurement errors, some random, some systematic, and some in-between (short-term systematic). Further, systematic errors may affect several individual items and, depending on their nature, may even affect items in more than one component of the MUF equation.

In principle, one can write down the complete model for a given MUF and calculate the variance of MUF by applying the propagation of errors formula given in the previous section. In practice, this is not done because of the hundreds of terms that would normally be included, except for a very simple material balance.

Some general procedures for propagating errors in the MUF equation, i.e., for calculating the variance of MUF are given. These procedures are based on strict application of the standard propagation of error formulas, but approximations may come into play when stating the assumptions on which the procedures (or general formulas) are based. Moderate departures from some of these assumptions have negligible effect, as can easily be demonstrated. If there is concern about the importance of a departure from a given assumption, more exact calculations can be made.

The procedures indicated are for calculation of the variance of element MUF; some extensions are required if the variance of isotope MUF is to be calculated. These extensions go beyond the scope of this presentation, but represent no new statistical ideas.

In calculating the variance of MUF, it is convenient to develop a hierarchy of classification consisting of items, batches, strata, and components.

An <u>item</u> is a primary unit which has a weight, volume, or NDA measurement associated with it. A number of items collectively form a <u>batch</u>, where a batch consists of all items that are related because they have a common element concentration factor. In the event the element factor is uniquely determined for each batch, then an item and a batch are identical, i.e., there is one item in that batch. A number of batches collectively form a <u>stratum</u>, which consists of all batches of like material. One has a certain amount of freedom in defining a stratum in a given application: strata of similar materials may be combined into a single stratum in order to reduce the amount of calculation at the expense of bending the assumptions somewhat. Finally, strata are combined to form a component of the MUF equation. There are the four MUF components identified earlier in the schematic equation.

With these classifications in mind, the following assumptions are made:

(1) All random, short-term systematic, and long-term systematic error standard deviations are known and are expressed on a relative basis. For example, a 0.4% relative standard deviation is expressed as 0.004.

(2) Within a given batch, the number of samples drawn and the number of analyses per sample are both constants.

(3) Within a given stratum, the number of items per batch is constant.

(4) No more than one scale or analytical method is used in a given stratum.

(5) A given element concentration factor cannot apply to more than one stratum.

The following notation is used.

x_{kqpt} = total element weight in stratum k, where the element weight is found using bulk measurement method q, sampling is from material type p, and analytical technique t is used. If measurement is by NDA, regard the NDA instrument as an analytical method. "Dummy" methods may be used for the bulk and sampling measurements.

NOTE: It may be that within a stratum, the same systematic error does not affect all items, i.e., there is a short term systematic error. Use parentheses to indicate the total element weight associated with "condition i" for a given measurement. For example:

$x_{kqpt(3)}$ = total element weight identified with condition 3 for analytical method t in stratum k

$x_{kq(2)pt}$ = total element identified with bulk method (e.g., scale) 2 in stratum k.

To continue,

δ	=	a relative standard deviation, subscripts identify a specific one.
s,g,r	=	first subscript on δ: s refers to a long term systematic error, g to a short term systematic error; r to a random error.
q,p,t	=	second, third, and fourth subscripts on δ; defined as for the subscripts on x; if the measurement method in question is a bulk method, replace p and t by dots, for example:
$\delta_{r.p.}$	=	random error standard deviation in sampling of material type p.
n_k	=	number of items per batch in stratum k
m_k	=	number of batches in stratum k
r_k	=	number of samples drawn in stratum k to estimate the batch element concentration factor
c_k	=	number of analyses per sample in stratum k
K	=	total number of strata
V(...)	=	variance of quantity within parentheses, for example,
$V(x_{kqpt})$	=	variance of element weight in stratum k,
V(MUF)	=	variance of MUF.

<u>NOTE</u>: s, g, and r subscripted on V is defined as when subscripted on δ; if V has no subscript, this refers to a total variance.

First, consider the random error variance of MUF. For stratum k, the random error variance of the total element weight is

$$V_r\,(x_{kqpt}) = x^2_{kqpt}\,(\delta^2_{rq..}/n_k m_k + \delta^2_{r.p.}/r_k m_k + \delta^2_{r..t}/c_k r_k m_k)\ .$$

To find V_r(MUF), $V_r(x_{kqpt})$ is summed over all the strata.

$$V_r(\text{MUF}) = \sum_{k=1}^{K} V_r(x_{kqpt})$$

Next, consider the short-term systematic error variance. The calculations indicated need only be performed for those measurements for which the first subscript on δ is g, i.e., for the non-zero short term systematic error variances.

For each combination of values, q(i), calculate

$$M_{q(i)..} = \sum_{k=1}^{K} A_k \, x_{kq(i)pt}$$

where A_k=+1 for input and beginning inventory strata and where A_k=-1 for output and ending inventory strata.

For each combination of values, p(i), calculate

$$M_{.p(i).} = \sum_{k=1}^{K} A_k \, x_{kqp(i)t}$$

where A_k is defined as above.

For each combination of values, t(i), calculate

$$M_{..t(i)} = \sum_{k=1}^{K} A_k \, x_{kqpt(i)}$$

where A_k is defined as above.

The short term systematic error variance of MUF is

$$V_g(\text{MUF}) = \sum_q \delta^2_{gq..} \sum_i M^2_{q(i)..} + \sum_p \delta^2_{g.p.} \sum_i M^2_{.p(i)} \; .$$

$$+ \sum_t \delta^2_{g..t} \sum_i M^2_{..t(i)} \; .$$

Finally, consider the long term systematic error variance of MUF.

For each value of q, calculate

$$M_{q..} = \sum_{k=1}^{K} A_k \, x_{kqpt}$$

where A_k=+1 for input and beginning inventory strata and A_k=-1 for output and ending inventory strata. Note that if the short-term systematic error calculations are performed for each value of q, then $M_{q..}$ may be found by summing the $M_{q(i)..}$ values for i. Similar statements hold for sampling and analytical errors.

For each value of p, calculate

$$M_{.p.} = \sum_{k=1}^{K} A_k \, x_{kqpt}$$

where A_k is defined as above.

For each value of t, calculate

$$M_{..t} = \sum_{k=1}^{K} A_k \, x_{kqpt}$$

where A_k is defined as above.

The long term systematic error variance of MUF is

$$V_s(\text{MUF}) = \sum_q M_{q..}^2 \, \delta_{sq..}^2 + \sum_p M_{.p.}^2 \, \delta_{s.p.}^2 + \sum_t M_{..t}^2 \, \delta_{s..t}^2 \, .$$

An example is now considered. This example deals with the plutonium MUF in a mixed oxide fuel fabrication plant. In this facility, there are 10 strata identified (K=10). There are 5 bulk measurement methods, (q=5); 6 material types, (p=6); and 4 analytical methods, (t=4). The error standard deviations are listed.

$\delta_{r1..} = 0.00025$	$\delta_{r.1.} = 0.0001$	$\delta_{r..1} = 0.0040$
$\delta_{r2..} = 0.00050$	$\theta_{r.2.} = 0.0080$	$\delta_{r..2} = 0.0050$
$\delta_{r3..} = 0.00040$	$\delta_{r.3.} = 0.035$	$\delta_{r..3} = 0.0060$
$\delta_{r4..} = 0$*	$\delta_{r.4.} = 0$*	$\delta_{r..4} = 0.20$
$\delta_{r5..} = 0.00040$	$\delta_{r.5.} = 0.004$	
	$\delta_{r.6.} = 0.020$	

*"dummy" methods

Stratum 1 is an input stratum consisting of containers of PuO_2. Stratum 2 is an output product stratum consisting of containers of sintered pellets. Stratum 3 is an output stratum consisting of dirty powder sent offsite for scrap recovery.

Stratum 4 is an output waste stream stratum consisting of containers of solid waste measured by NDA. Stratum 5 is a beginning inventory stratum consisting of containers of mixed oxide powder. Stratum 6 is a beginning inventory stratum containing the same kind of material as output stratum 3. Stratum 7 is a beginning inventory stratum consisting of containers of grinder swarf. Strata 8, 9, and 10 are ending inventory strata containing the same kinds of materials as strata 5, 6, and 7 respectively.

The pertinent parameter values are given in the following table.

	Stratum (k)									
	1	2	3	4	5	6	7	8	9	10
n_k	32	200	1	1	20	1	1	20	1	1
m_k	24	198	10	100	15	4	6	18	5	3
r_k	4	5	1	1	3	1	1	3	1	1
c_k	2	1	1	1	1	1	1	1	1	1
q	1	2	3	4	5	3	3	5	3	3
p	1	2	3	4	5	3	6	5	3	6
t	1	2	3	4	3	3	2	3	3	2
x_{kqpt}(1)	1536	1485	9.0	0.4	112.5	3.6	4.5	135	4.5	2.25

(1) entries are in kg Pu.

For the random error variance, calculate

$V_r\ (x_{1111}) = 0.197046\ kg^2$ Pu

$V_r\ (x_{2222}) = 0.198261\ kg^2$ Pu

$V_r\ (x_{3333}) = 0.010215\ kg^2$ Pu

$V_r\ (x_{4444}) = 0.000064\ kg^2$ Pu

$V_r\ (x_{5553}) = 0.014632\ kg^2$ Pu

$V_r\ (x_{6333}) = 0.004086\ kg^2$ Pu

$V_r\ (x_{7362}) = 0.001435\ kg^2$ Pu

$V_r\ (x_{8553}) = 0.017558\ kg^2$ Pu

$V_r\ (x_{9333}) = 0.005108\ kg^2$ Pu

$V_r\ (x_{10,362}) = 0.000717\ kg^2$ Pu

V_r is then computed

$$V_r = 0.197046 + 0.198261 + \ldots + 0.000717$$
$$= 0.449122 \text{ kg}^2 \text{ Pu}$$

To continue, for the short-term systematic error, assume that there are short term systematic errors associated with the analytical methods due, in part, to system recalibrations during the one-year material balance period. Also assume that after the first 10 batches of PuO_2 powder receipts are weighed, the scale is replaced by another of similar design. This has no effect on the random error variance, but the introduction of this second scale can be handled as a short term systematic error; since this second scale has the same design as the first one, the effect is the same as if the first scale had simply been recalibrated.

The following error parameter values are given.

$\delta_{g1..} = 0.00010$

$\delta_{g..1} = 0.0013$
$\delta_{g..2} = 0.0016$
$\delta_{g..3} = 0.0020$
$\delta_{g..4} = 0.06$

For the weighing of the PuO_2 receipts,

$x_{11(1)11} = 640$ $\qquad$ $x_{11(2)11} = 896$

so that

$M_{1(1)..} = 640$ $\qquad$ $M_{1(2)..} = 896$

For the analytical methods, assume that the following quantities of materials are associated with the various shifts in the systematic errors (all quantities in Kg Pu):

<u>Stratum 1</u> $\quad x_{1111(1)} = x_{1111(2)} = x_{1111(3)} = 512$

<u>Stratum 2</u> $\quad x_{2222(1)} = x_{2222(2)} = x_{2222(3)} = 495$

<u>Stratum 3</u> $\quad x_{3333(1)} = 0,\ x_{3333(2)} = 9.0$

<u>Stratum 4</u> $\quad x_{4444(1)} = 0.16,\ x_{4444(2)} = 0.24$

<u>Stratum 5</u> $\quad x_{5553(1)} = 112.5,\ x_{5553(2)} = 0$

<u>Stratum 6</u> $\quad x_{6333(1)} = 3.6,\ x_{6333(2)} = 0$

<u>Stratum 7</u> $x_{7362(1)} = 4.5,\ x_{7362(2)} = x_{7362(3)} = 0$

<u>Stratum 8</u> $x_{8553(1)} = 0,\ x_{8553(2)} = 135$

<u>Stratum 9</u> $x_{9333(1)} = 0,\ x_{9333(2)} = 4.5$

<u>Stratum 10</u> $x_{10,362(1)} = x_{10,362(2)} = 0,\ x_{10,362(3)} = 2.25$

Then,

$$M_{..1(1)} = M_{..1(2)} = M_{..1(3)} = 512$$

$$M_{..2(1)} = -495 + 4.5 = -490.5$$

$$M_{..2(2)} = -495$$

$$M_{..2(3)} = -495 - 2.25 = -497.25$$

$$M_{..3(1)} = 112.5 + 3.6 = 116.1$$

$$M_{..3(2)} = -9.0 - 135 - 4.5 = -148.5$$

$$M_{..4(1)} = -0.16$$

$$M_{..4(2)} = -0.24 .$$

The short term systematic error variance of MUF is then calculated.

		kg^{2}Pu
$V_g(MUF)$	$= (0.00010)^2\ [(640)^2 + (896)^2]$	$= 0.012124$
	$+ (0.0013)^2\ [(512)^2 + (512)^2 + (512)^2]$	$= 1.329070$
	$+ (0.0016)^2\ [(-490.5)^2 + (-495)^2 + (-497.25)^2]$	$= 1.867154$
	$+ (0.0020)^2\ [(116.1)^2 + (-148.5)^2]$	$= 0.142126$
	$+ (0.06)^2\ [(-0.16)^2 + (-0.24)^2]$	$= 0.000300$

$$V_g(MUF) = 3.359774 \text{ Kg}^2 \text{ Pu}$$

Next, consider the long term systematic error variance of MUF. The following error parameter values are given:

$\delta_{s1..} = 0.00020$	$\delta_{s.1.} = 0$	$\delta_{s..1} = 0.0007$
$\delta_{s2..} = 0.00035$	$\delta_{s.2.} = 0.0010$	$\delta_{s..2} = 0.0012$

$\delta_{s3\cdot\cdot} = 0.00025$	$\delta_{s\cdot 3\cdot} = 0.015$	$\delta_{s\cdot\cdot 3} = 0.0015$
$\delta_{s4\cdot\cdot} = 0$*	$\delta_{s\cdot 4\cdot} = 0$*	$\delta_{s\cdot\cdot 4} = 0.08$
$\delta_{s5\cdot\cdot} = 0.00025$	$\delta_{s\cdot 5\cdot} = 0.0024$	
	$\delta_{s\cdot 6\cdot} = 0.008$	

*"dummy" method

From the data table given earlier, the M values are calculated. For the analytical methods, the M's are easily calculated using the short term systematic error calculations. All units are in kg Pu.

$M_{1\cdot\cdot} = 1536$

$M_{2\cdot\cdot} = -1485$

$M_{3\cdot\cdot} = -9.0 + 3.6 + 4.5 - 4.5 - 2.25 = -7.65$

$M_{5\cdot\cdot} = 112.5 - 135 = -22.5$

$M_{\cdot 2\cdot} = -1485$

$M_{\cdot 3\cdot} = -9.0 + 3.6 - 4.5 = -9.9$

$M_{\cdot 5\cdot} = 112.5 - 135 = -22.5$

$M_{\cdot 6\cdot} = 4.5 - 2.25 = 2.25$

$M_{\cdot\cdot 1} = 1536$

$M_{\cdot\cdot 2} = - 490.5 - 495 - 497.25 = -1482.75$

$M_{\cdot\cdot 3} = 116.1 - 148.5 = -32.4$

$M_{\cdot\cdot 4} = -0.4$

The long term systematic error variance of MUF is calculated term by term.

	kg^2 Pu
V_s (MUF) $= (1536)^2 (0.00020)^2$	(= 0.094372)
$+ (-1485)^2 (0.00035)^2$	(= 0.270140)
$+ (-7.65)^2 (0.00025)^2$	(= 0.000004)
$+ (-22.5)^2 (0.00025)^2$	(= 0.000032)
$+ (-1485)^2 (0.0010)^2$	(= 2.205225)
$+ (-9.9)^2 (0.015)^2$	(= 0.022052)

$$+ (-22.5)^2 (0.0024)^2 \qquad (= 0.002916)$$
$$+ (2.5)^2 (0.008)^2 \qquad (= 0.000324)$$
$$+ (1536)^2 (0.0007)^2 \qquad (= 1.156055)$$
$$+ (-1482.75)^2 (0.0012)^2 \qquad (= 3.165908)$$
$$+ (-32.4)^2 (0.0015)^2 \qquad (= 0.002362)$$
$$= (-0.4)^2 (0.08)^2 \qquad (= \underline{0.001024})$$
$$V_s \text{ (MUF)} = 6.920414 \text{ kg}^2 \text{ Pu}$$

Therefore, summing, the variance of MUF is

$$V \text{ (MUF)} = 0.449122 + 3.359774 + 6.920414 = 10.729310 \text{ kg}^2 \text{ Pu}$$

$$\sqrt{V(\text{MUF})} = 3.276 \text{ kg Pu, or } 0.213\% \text{ of input.}$$

B. Variance of a Difference Statistic

Paired difference data arise in a number of situations in the safeguarding of nuclear materials. Such data are those in which a measured value obtained by one measurement method is compared on a one-by-one basis with a corresponding measured value for the same item obtained by a second method. This situation occurs with shipper-receiver data and also with inspection data. Also, within a facility, one measurement method may be compared with another by measurement of a number of items using both methods.

The difference statistic for inspection data is of particular interest. (A shipper-receiver difference may be regarded as a special case.) The inspector samples and measures a number of items in each of the material strata and compares his measured results with those given by the facility operator. The average difference per item in stratum k is denoted by $\bar{d}_k$. If there are N_k total items in stratum k, then $N \bar{d}_k = D_k$ is the projected total difference between the operator and the inspector in stratum k. This is algebraically summed over all strata to estimate the impact on the reported MUF of the operator-inspector differences. The key assumption is that the inspector results are unbiased, so the purpose of the inspection is either to confirm that the operator's reported MUF is unbiased, i.e., that the total difference statistic does not differ significantly from zero, or else to adjust the Operator's MUF for biases as estimated from the paired difference data. The overall difference statistic, called the $\hat{D}$ statistic, if of the form

$$\hat{D} = \sum_{k=1}^{K} A_k D_k$$

where $A_k = \pm 1$, depending on the stratum. For input and beginning inventory strata, $A_k = 1$ and for output and ending inventory strata, $A_k = -1$. With all differences being of the form: operator-inspector, and with $\hat{D}$ defined in this way, then $(MUF-\hat{D})$ is the MUF value adjusted for operator bias.

General formulas are given to permit simple calculation of the variance of $\hat{D}$. These formulas are based on assumptions stated below. As was true for the calculation of the variance of MUF by general formula, the assumptions will rarely if ever be completely valid in given applications. However, experience has shown that this is not a great difficulty, since in many cases, even moderate departures from the assumptions have very little effect. Further, if one has concern about the validity of the general formulas in a given instance, they can readily be altered as appropriate to accommodate a different set of circumstances.

The assumptions about the facility data were stated in Section V.A. The additional assumptions relative to the inspection are as follows:

(1) For samples of items within a stratum, the inspector also makes measurements. He need not necessarily make the same type of measurements as the facility, e.g., he may use non-destructive assay methods to a much greater extent than does the facility operator.

(2) The inspector and the facility use the same material sampling procedures, and hence, systematic errors in sampling will cancel. The effects of changing this particular assumption on the calculations should be quite apparent.

(3) When there are batches within a stratum, the inspector may first sample batches at random and then measure the same number of items in each batch sampled.

(4) The inspector may utilize a number of laboratories to analyze the samples, but for a given stratum, all use the same analytical method.

The notation is an extension to that given earlier. The quantity y_{kqpt} is defined as was x_{kqpt}, except that y refers to an inspector value. The measurement methods q,p,t refer to <u>his</u> methods.

Note: As was the case with the facility operator, it may be that within a stratum, the same systematic error does not affect all items, i.e., there is a short term systematic error. Use parentheses to indicate the total element weight associated with "condition i" for a given measurement.

Since, under assumption (3) of the previous paragraph, the inspector may utilize a number of laboratories, this concept is extended to accommodate this possibility. Specifically,

$y_{kqpt(i(j))}$ = total element weight in stratum k as determined by the inspector using the indicated measurement methods, and for those items measured under condition j within laboratory i.

If need be, this idea can be extended further using additional classifications that may be either crossed or nested. However, the extension just indicated should be adequate to cover the great majority of applications.

To continue with the notation, δ with subscripts still denotes a relative standard deviation. The first subscript of r, s, or g is defined as below. If the first subscript is h, this refers to a short term systematic error within another such error, i.e., to a condition or time effect within a laboratory. Subscripts 2, 3, and 4 are defined as before. A fifth subscript is either x to refer to an operator standard deviation or y to refer to one for the inspector. Further, let u_k, w_k, v_k, and a_k denote inspector parameters associated with stratum k:

u_k = number of batches sampled by the inspector.

w_k = number of items per sampled batch for which the inspector makes bulk measurements

v_k = number of samples drawn by the inspector per sampled batch to determine the element factor

a_k = number of analyses performed by the inspector per sample

With this notation in mind, formulas needed to compute the random error variance of $\hat{D}$ are now given.

For stratum k, the random error variance of $\hat{D}_k$ due to measurement errors committed by the facility is

$$V_{rx}(\hat{D}_k) = x^2_{kqpt}\,[\delta^2_{rq\cdot\cdot x}/u_k w_k + \delta^2_{r\cdot p\cdot x}/u_k r_k + \delta^2_{r\cdot\cdot tx}/c_k u_k r_k] \; .$$

That due to the inspector's errors of measurement is

$$V_{ry}(\hat{D}_k) = y^2_{kqpt}\,[\delta^2_{rq\cdot\cdot y}/u_k w_k + \delta^2_{r\cdot p\cdot y}/u_k v_k + \delta^2_{r\cdot\cdot ty}/a_k u_k v_k] \; .$$

The variance of $\hat{D}_k$ is

$$V_r(\hat{D}_k) = V_{rx}(\hat{D}_k) + V_{ry}(\hat{D}_k) \; .$$

The variance of $\hat{D}$ is then found by summing $V_r(\hat{D}_k)$ over the strata.

$$V_r(\hat{D}) = \sum_{k=1}^{K} V_r(\hat{D}_k)$$

In giving the formulas needed to compute the short-term systematic error variance, note that the calculations indicated need only be performed for those measurements for which the first subscript on δ is g or h, i.e., for the non-zero short term systematic error variances.

For each combination of values q(i), calculate

$$M_{q(i)..x} = \sum_{k=1}^{K} A_k \, x_{kq(i)pt}$$

where A_k = +1 for input and beginning inventory strata and where A_k = -1 for output and ending inventory strata.

For each combination of values t(i), calculate

$$M_{..t(i)x} = \sum_{k=1}^{K} A_k \, x_{kqpt(i)}$$

where the A_k are defined as before.

The contribution to the short term systematic error variance of $\hat{D}$ due to facility measurements is

$$V_{gx}(\hat{D}) = \sum_q \delta^2_{gq..x} \sum_i M^2_{q(i)..x} + \sum_t \delta^2_{g..tx} \sum_i M^2_{..t(i)x} \; .$$

For the inspector, each combination of values q(i), calculate

$$M_{q(i)..y} = \sum_{k=1}^{K} A_k \, y_{kq(i)pt}$$

with the A_k defined as before.

For each combination of values t(i(j)), calculate

$$M_{..t(i(j))y} = \sum_{k=1}^{K} A_k \, y_{kqpt(i(j))}$$

with A_k defined as above. Finally, for each combination t(i), calculate

$$M_{..t(i)y} = \sum_{k=1}^{K} M_{..t(i(j))y} \; .$$

The contribution to the short term systematic error variance of $\hat{D}$ due to inspector measurements is

$$V_{gy}(\hat{D}) = \sum_{q} \delta^2_{gq..y} \sum_{i} M^2_{q(i)..y} + \sum_{t} \delta^2_{h..ty} \sum_{i,j} M^2_{..t(i(j))y}$$

$$+ \sum_{t} \delta^2_{g..ty} \;{}_{i}\; M^2_{..t(i)y} \; .$$

The total short term systematic error variance of $\hat{D}$ is

$$V_g(\hat{D}) = V_{gx}(\hat{D}) + V_{gy}(\hat{D}) \; .$$

Next, consider the long term systematic error variance of $\hat{D}$. First, for the facility measurements, for each value of q, calculate

$$M_{q..x} = \sum_{k=1}^{K} A_k \, x_{kqpt}$$

where A_k = +1 for input and beginning inventory strata and A_k = −1 for output and ending inventory strata. Note that if the short-term systematic error calculations are performed for each value of q, then $M_{q..x}$ may be found by summing the $M_{q(i)..x}$ values over i. Similar statements hold for the equations to follow.

For each value of t, calculate

$$M_{..tx} = \sum_{k=1}^{K} A_k \, x_{kqpt}$$

with the A_k defined as above.

The long term systematic error variance of $\hat{D}$ due to facility measurements is

$$V_{sx}(\hat{D}) = \sum_q M^2_{q..x}\ \delta^2_{sq..x} + \sum_t M^2_{..tx}\ \delta^2_{s..tx}\ .$$

For the inspector measurements, for each value of q, calculate

$$M_{q..y} = \sum_{k=1}^{K} A_k\ y_{kqpt}$$

and for each value of t, calculate

$$M_{..ty} = \sum_{k=1}^{K} A_k\ y_{kqpt}$$

where A_k is again defined as above. The long term systematic error variance of $\hat{D}$ due to inspector measurements is

$$V_{sy}(\hat{D}) = \sum_q M^2_{q..y}\ \delta^2_{sq..y} + \sum_t M^2_{..ty}\ \delta^2_{sq..y}\ .$$

Finally, the total systematic error variance of D is

$$V_s(\hat{D}) = V_{sx}(\hat{D}) + V_{sy}(\hat{D})\ .$$

Since the calculations are very similar to those used in the calculation of the variance of MUF, an example is not included here.

VI. STATISTICAL INFERENCE BASED ON INSPECTION DATA

Stated very simply, the purpose of an inspection is to provide assurance that the material balance data for a facility properly reflect the state of control that exists in that facility, and further, that this state of control is satisfactory. In planning for inspection, it is assumed that the facility accounting data may misrepresent the actual amounts of material in discrete items. Although such data misrepresentations may clearly occur because of innocent reasons, e.g., because of mistakes in recording the measured data, it is assumed for planning purposes that data misrepresentation occurs intentionally in order to mask diversion. This assumption is made in order to provide assurance that the inspection is effective and credible against all possible combinations of understatements and overstatements of material. To be effective and credible, the inspection must guard against the worst possible set of circumstances; this worst possible set corresponds to actions that would be taken by a diverter attempting to conceal diversion through data falsification.

Inspection activities, while perhaps quite varied in a number of respects, e.g., measurement complexity, cost, accuracy, etc. may be broadly classified as falling into one of two categories -- attributes or variables inspection. In attributes inspection, the item inspected is classified as being either acceptable or not acceptable (i.e., a defect) on the basis of the measurement. Attributes inspection has nothing to do with the quality of the measurement, but rather, with the end use to which the measurement is put. Variables inspection, on the other hand, assigns a measured value to each item inspected, and the measured values for a group of items are combined in some way to provide a statistic, or a function of the observations (specifically, the $\hat{D}$ statistic), used in the evaluation.

In attributes inspection, a sufficient number of items are measured so as to detect some missing a priori amount, spread over all strata, with a specified level of assurance. The a priori amount is called the goal quantity, designated by M units (say, kg of element), while the probability of detecting this missing amount is designated by $(1-\beta)$. A minimum amount of inspection is required if a zero acceptance number plan is used, i.e., if "detection" occurs when a single "defective" item is found in the sample. (The actions to take in the event of detection are not specified; it may involve 100% attributes inspection, at least in some strata.) A simple formula provides the sample size in stratum k in this event:

$$n_k = N_k \ (1-\beta^{1/D})$$

where n_k is the sample size, N_k the number of items in the population, and D the number of defect items to be detected. D is related to M, to the amount by which an item may be defected, and to the measurement capability of the attributes tester in the stratum in question.

Turning to the variables data analysis, the $\hat{D}$ statistic referred to earlier is the key statistic derived from variable inspection. Procedures for calculating the variance of $\hat{D}$ were given in Section V. From an inspection planning viewpoint, the problem is to choose the number of measurements to perform in each stratum. This is done to meet the following type criterion:

Criterion: If the true value for the difference statistic, D, is M units, detect this fact with a statistical test using $\hat{D}$ with probability $(1-\beta)$. The significance level of the test is α. This is a common type statistical problem in selecting a sample size and critical value, but is somewhat complicated by a number of considerations:

(1) One must not only determine the entire sample size, but must also allocate the total sample size among the various strata. This is done by allocating such that the variance of $\hat{D}$ is minimized for fixed total sample size.

(2) Because of limitations imposed by systematic errors, it may not be possible to meet the criterion. In this case, the relationship between sample size and β is examined and some compromising value is chosen for the sample size.

(3) The variance of $\hat{D}$ under the alternative that its mean is not zero may be larger than that under the null hypothesis that its mean is zero. This will affect the sample size, and, in planning, an inflation factor on this variance should be applied.

In a general solution to the problem, there are a number of parameters that may be identified. In addition to assigning values to M, α, β, and C^2 (the variance inflation factor), one can also perform the planning for the $(MUF-\hat{D})$ statistic rather than the D statistic. The general formula is solved for the specific case in which $\alpha = \beta = 0.05$, $c^2 = 4$, and the $\hat{D}$ statistic is used. In this event, the sample size is inversely proportional to

$$0.2053m^2 - 0.1642m \quad \sqrt{6.0886m^2}$$

where m is the ratio of M to the systematic error standard deviation of $\hat{D}$.

Having planned the inspection, it, together with the value for the facility determined variance of MUF, may be evaluated from point of view of their combined ability to detect a specified missing amount of material, specifically, the goal amount M.

In inspection planning, it is assumed that all M units are diverted by the particular route to be responded to by the given inspection. For example, in determining the sample size for attributes inspection in stratum k, it is assumed that all M units are diverted through large defects (data falsifications) in that particular stratum. Clearly, if any amount smaller than M units is so diverted, the probability of detection will be less than the design value of $(1-\beta)$ for that particular part of the inspection.

There are, of course, a virtually limitless number of strategies that might be used by the diverter to accumulate his goal quantity of M units in a material balance period. For any given strategy, one can calculate the probability of non-detection (or its complement, the probability of detection) for the statistical tests employed. "Detection" occurs if at least one of the following conditions occurs:

(1) A gross defect is found in a least one of the strata using the attributes tester

(2) A defect is found in at least one of the strata using the variables tester in the attributes mode.

(3) The absolute value of the $\hat{D}$ statistic exceeds its critical value, i.e., there is statistical evidence that the mean of $\hat{D}$ is not zero.

(4) The operator's calculated MUF exceeds its critical value, i.e., there is statistical evidence that the mean value of MUF is not zero.

As an alternate to steps (3) and (4), one may not perform separate tests of significance for $\hat{D}$ and MUF but may choose to detect the combined effects of two diverter strategies (diversion by small data falsifications and into MUF). Thus, (3) and (4) may be replaced by:

(5) The (MUF-$\hat{D}$) statistic exceeds its critical value, i.e., there is statistical evidence that the mean value of (MUF-$\hat{D}$) is not zero.

There are distinct operational advantages to an inspector in using (MUF-$\hat{D}$) as the test statistic rather than $\hat{D}$ and MUF separately. Most importantly, both $\hat{D}$ and MUF require information about the operator's systematic errors. This information is often difficult to develop or, if available, may be poorly based and somewhat unreliable. On the other hand, the (MUF-$\hat{D}$) statistic is independent of the operator's systematic errors. It does, of course, require information about the inspector's systematic errors but such information is easier to derive and, from the inspector's viewpoint at least, should be more reliable.

As another advantage of the (MUF-$\hat{D}$) statistic, when calculating the probability of non-detection by the $\hat{D}$ and MUF tests separately administered, one must take into account the covariance between $\hat{D}$ and MUF. This can be done, but the computations can be complicated involving table look-up in a table of bivariate normal distribution. Computer programs do exist that perform the calculation of non-detection for $\hat{D}$ and MUF, but unless such a program is available to the user, or unless a table of the bivariate normal distribution is available, the non-detection probabilities for the $\hat{D}$ and MUF tests in combination cannot even be calculated. This is not the case with the $(MUF-\hat{D})$ statistic. In passing, it is noted that one cannot simply ignore the covariance between $\hat{D}$ and MUF and assume that the test statistics are independent; this is far from true and gives incorrect and misleading results.

The interesting relationship among MUF, $\hat{D}$, and $(MUF-\hat{D})$ variance is:

$$V(MUF-\hat{D}) = V(\hat{D}) - V(MUF) + 2V_o .$$

This may also be written as:

$$\text{Covariance } (\hat{D}, MUF) = V(MUF) - V_o$$

where V_o is the variance component consisting of systematic errors common to the operator and the inspector.

These equations are basic in the evaluation of the inspection plans. Since $V(\hat{D})$, V_o, and $V(MUF)$ will already have been calculated, $V(MUF-\hat{D})$ follows immediately.

Restricting further attention to points (1), (2), and (5) detailed above, the probability of non-detection for a given diverter strategy reduces to

$$Q = \beta^{a_2} Q_1$$

where a_2 is the fraction of M diverted into some combination of large and medium data falsifications, where β is the design parameter for all strata in the attributes inspection (or the largest such value if β is not the same for all strata), and Q_1 is the probability of non-detection of an amount $(1-a_2)M$ with the $(MUF-\hat{D})$ test. The probability Q_1 is a function of how the diverter splits the amount $(1-a_2)M$ into MUF and into $\hat{D}$. Thus, the strategy space open to the diverter involves his choice of a_2 and of his further choice on how much of the remaining amount of M, the goal quantity, is diverted into MUF.

The quantity Q_{max} is that value of Q corresponding to optimal diverter strategy, i.e., that strategy which yields the largest value for Q.

An example application dealing with the inspection of a low enriched uranium fuel fabrication plant is given. For this plant,

$$M = 1500 \text{ kg U}$$

$$\sqrt{V(MUF)} = 212 \text{ kg U}$$

$$\sigma_s = 296 \text{ kg U (systematic error in } \hat{D})$$

$$\sqrt{V_r(\hat{D})} = 224 \text{ kg U, corresponding to an inspection sample size of 40}$$

$$V_o = 0$$

$$\sqrt{V(MUF-\hat{D})} = 305 \text{ kg U, under the hypothesis of no diversion}$$

$$\beta = 0.05 \ .$$

The probability of nondetection as a function of a_2 is tabulated.

a_2	a_2	Q_1	Q
0	1.0000	0.0213	0.0213
.1	0.7411	0.0424	0.0314
.2	0.5493	0.0779	0.0428
.3	0.4071	0.1324	0.0539
.4	0.3017	0.2090	0.0631
.5	0.2236	0.2974	0.0665
.6	0.1657	0.4110	0.0681
.7	0.1228	0.5663	0.0695
.8	0.0910	0.7454	0.0678
.9	0.0675	0.8753	0.0591
1.0	0.0500	0.9500	0.0475

Q_{max} is about 0.07 so that the minimum probability of detection is about 0.93 for this example.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #13a: ADVANCED SNM ACCOUNTING AND CONTROL SYSTEMS FOR BULK PROCESSING FACILITIES

SPEAKER: William A. Higinbotham

Brookhaven National Laboratory
Upton, New York USA

Thursday, May 29, 1980
8:30 p.m.

BIOGRAPHY

Education: Williams College, AB - Physics 1932; Williams College, Hon D. Sc 1963; Cornell graduate school - no degree.

Present Position: senior scientist, Brookhaven National Lab.

Present Duties: Safeguards Studies and Coordination

Past Positions: Electronics, Nuclear Instrumentation

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #13b: ADVANCED SNM ACCOUNTING AND CONTROL SYSTEMS FOR BULK PROCESSING FACILITIES

SPEAKER: Dr. John J. Malanify

Los Alamos Scientific Laboratory
Los Alamos, New Mexico USA

Thursday, May 29, 1980
8:30 p.m.

BIOGRAPHY

Education: Rensselaer Polytechnic Institute, Physics, B.S. and Ph.D

Present Position: Group Leader LASL Group Q-3 (Safeguards Accountability Subsystems Development)

Present Duties: Q-3 is responsible for development of the Dynamic Nuclear Materials Accountability and Control (DYMAC) system.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #13: ADVANCED SNM ACCOUNTING AND CONTROL SYSTEMS FOR BULK PROCESSING FACILITIES

The basic components of an advanced materials accounting and control system are described through a "video tour" of an operating in-plant system. Emphasis is placed upon the integration of these components to achieve timely safeguards material accountability and control.

After the session, participants will be able to

1. Identify the basic components of an advanced system of nuclear materials accountability and control.

2. Describe the integration of these components into a complete system, and discuss applications to specific problems.

SESSION 13: THE DYMAC SYSTEM: STATUS AND EXPERIENCE

J. Malanify
Los Alamos Scientific Laboratory

As nuclear materials safeguards research and development projects mature, it becomes essential that the improved instrumentation and techniques be applied in an operating plant environment. Only then can the resulting advantages and disadvantages be judged. The Los Alamos Scientific Laboratory has been developing a near real-time, advanced nuclear materials accountability system, DYMAC, at its Plutonium Processing Facility.[1,2] This system will demonstrate the applicability of these techniques and provide a basis for evaluating wider implementation.

The new facility houses a wide variety of processes, including metal-to-oxide conversion, fuel pellet fabrication, and scrap recovery. The first nuclear material was received in January 1978, and the DYMAC system has been accounting for the material since that time.

The processing system and the accountability system have been installed and developed in parallel. At this time, the facility is virtually complete. The responsibility for continued routine operation and maintenance of the accountability system is being transferred from the Safeguards Research and Development staff to the Operational Safeguards staff.

The facility has been divided into 17 distinct accountability areas, called material balance areas (MBAs). Material is permitted to cross such boundaries only on a measured basis; therefore, the resulting inventory differences can be localized. The material balance is closed at three levels: the station, or entire facility balance, is monitored by the Nuclear Materials Officer (NMO). The account, or MBA balance, is monitored by the account supervisor, but all the process data are input by process personnel, and the balance is closed at the unit process area, as well. A material balance is maintained around each account by measuring the material entering and leaving it. If, however, the material is in a sealed can, the recorded value is accepted.

DYMAC embraces the concept of maintaining a material balance around the unit process by measured values (see Fig. 1). The unit process may be a glovebox or part of a glovebox, or two or more adjoining gloveboxes. This approach provides good information on the location of the material. Furthermore, some unit processes may be able to complete their batches and have time to perform a cleanout. This allows the removal of scrap and holdup, to reduce the material in process (MIP) in that area to a known value, zero, thereby improving the balance accuracy. These cleanouts can be performed for a localized area without having to wait for a total plant shut-down.

The heart of the DYMAC system is a dedicated minicomputer which receives information on activities and transactions within the Plutonium Processing Facility, and can provide at any time the location, quantity, and composition of all special nuclear material (SNM). Nondestructive assay (NDA) instruments

SCHEMATIC OF A DYMAC UNIT PROCESS

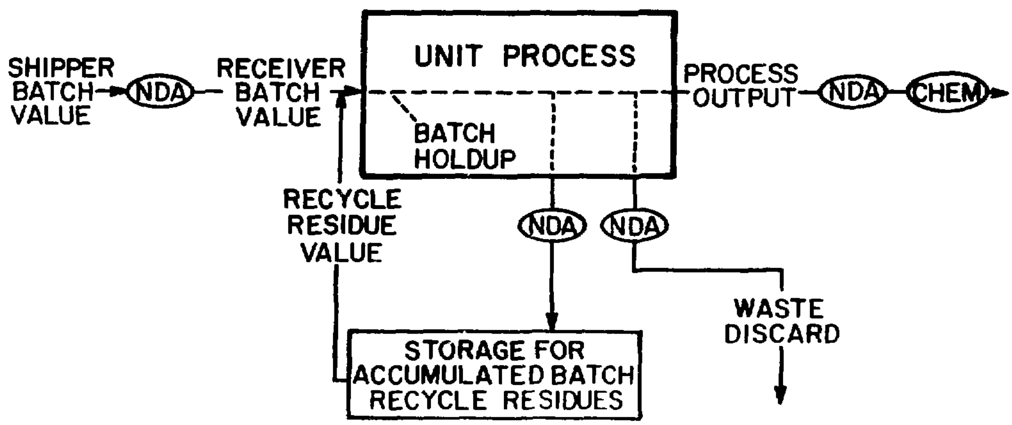

Fig. 1. Based on in-line NDA instruments, DYMAC maintains a material balance around each unit process.

are located strategically throughout the plant. Measurements made with this instrumentation are sent to the computer, either directly or by operator intervention, at 40 computer terminals located throughout the plant (see Fig. 2).

The present complement of NDA instrumentation consists of 38 digital electronic balances, 3 solution assay instruments for measuring plutonium content in liquid samples, 2 segmented gamma scanners for measuring plutonium content of scrap, and 19 thermal neutron coincidence counters for the assay of plutonium in bulk.

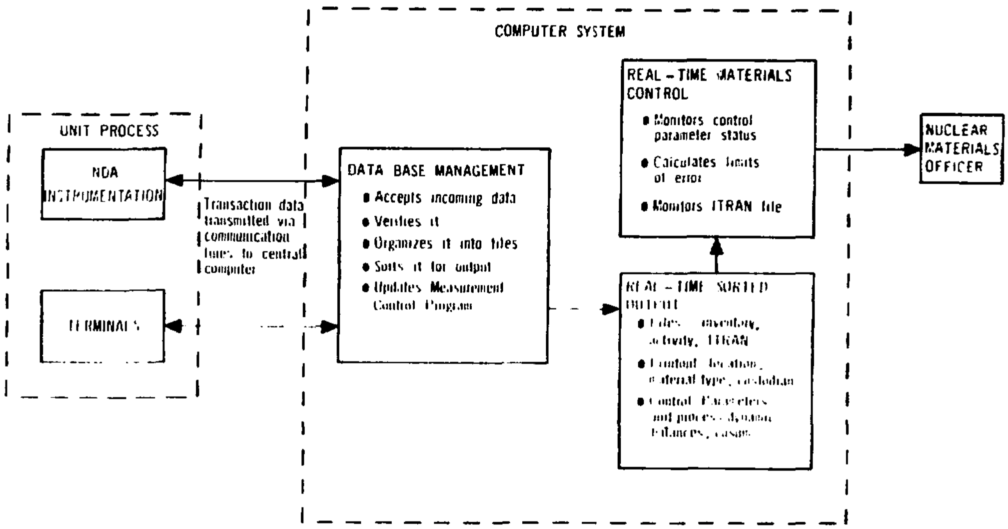

Fig. 2. The DYMAC system configuration.

The fundamental requirement of DYMAC is that, whenever a significant change is made in a batch, or when a batch moves from one area to another, the computer is notified of this action and information is sent to the computer to characterize the change. The computer uses this information to generate a computer transaction. No movement of the sample, nor change in its character, takes place without the computer being notified, or without the computer generating a transaction indicating the change.

It is possible for transactions to create new items by dividing old ones or by combining several items. Each new item created involves a transaction between the old item and the new, indicating the amount of material transferred. Using the acquired data, the computer provides reports which indicate the location of an item, its chemical form, and its SNM content. Other reports provide additional information, such as the inventory of an account or the sequence of processing steps which produced an item.

An inventory item is identified by its DYMAC name, which is the account number, the material type, and the item ID. These are the first 3 entries in the inventory record--there are 20 other entries. Among them are (1) receipt area, which is the unit process area; (2) physical location of the material, which is the station or glovebox number; (3) shelf, if the material is in a vault; (4) item description, which is the physical form of the material; (5) SNM value; (6) enrichment; (7) seal number; (8) bulk value; and (9) date and time.

Two inventory-by-location reports can be produced, a real-time report and an overnight report. The real-time report lists all of the items at a requested location, and gives its receipt area, SNM value, bulk value, shelf location, physical description, and seal number. This report can call for as many locations as desired. The overnight report reads out all the information in each record by location. In addition, it gives subtotals of SNM and isotopic weights by material type, with a grand total of all SNM and isotopic weights at the end of the report.

The total plant inventory cannot be determined by these inventory reports alone, because when an item is in transit, it is removed from the inventory file and entered into the in-transit, ITRAN, file. These two files together do, however, provide a statement of the total inventory at the time the request is made.

At each unit process all the data needed to prepare the inventory file, the transaction file, and the in-transit file are provided. Some of it is entered by the process operator, and some by the computer. Just what is entered by each depends on the kind of process being carried out. The information that must be entered by one or the other, are the DYMAC name, receipt area, project, person, location, shelf, special designator, item description, date/time, uranium or plutonium enrichment, uncertainty in enrichment (five isotopes can be recorded), impurities, condition of ending inventory, seal number, instrument code, bulk value, units, verification amount, and verification instrument. Other elements of the database are generated in the computer and maintained in special files.

Each process area has a transaction list that the operator can call up on the display of his computer terminal. After a transaction has been selected from the list, a sequence of questions will appear on the terminal screen. The operator answers them one by one. At the end of the questioning, a full display will appear on the screen, to show the operator what he has entered. A sample display is shown in Table I. This is the operator's opportunity to check the entries to be sure the data are correct before notifying the computer to update the transaction file and the inventory file.

The transaction sequence using the SEND/RECEIVE transaction is as follows:

a) The sender initializes the transaction and specifies the receiver by account number. If a measurement is to be made, a measurement code is entered to identify the measuring instrument.

b) If a measurement is made, the data, along with the item's DYMAC name, are sent to the computer by the person making the measurement.

c) The receiver confirms receipt of the item by completing the transaction, and the item is removed from the ITRAN file. Time limits are set for the amount of time an item may remain in the ITRAN file. Any item overdue will be reported to the Nuclear Materials Officer, and it is his responsibility to investigate and ensure completion of the transaction.

Two kinds of audit trails are required. One is the forward audit trail, which shows the sequence of events from the origin of the item to its final disposition. This is most helpful when an item cannot be physically located. The other is the backward audit trail. It is most helpful when a deficiency is discovered in an item. Backward tracing shows the sequence of events that actually produced the item, and this sequence can be compared with the planned sequence. This should be useful in identifying the origin of the discrepancy. To follow a forward and backward audit trail, the FROM and TO information must

TABLE I

TRANSACTION NUMBER 045N9
TRANSACTION MADE ON 9/19/78 AT 10:48
FROM PERSON: HGM TO PERSON:

NUMBER	********** FIELD **************	FROM **********	TO *******************
1,2	ITEM ID	FS5301	SC5301
3,4	ACCOUNT	711	711
5,6	RECEIPT AREA	OB	OB
7,8	PROJECT	413	413
9,10	SPECIAL DESIGNATOR	S1	S1
11,12	LOCATION	G133	G133
13,14	SHELF		
15,16	ITEM DESCRIPTION	CA1	DA9
17	"FROM" REMARKS: FEED STOCK IN OXIDE BLENDING		
18	"TO" REMARKS: SCRAP FROM OXIDE BLENDING		
19	DESTINATION:		
20,21	SNM AMOUNT: 4.0 G OF TYPE 54	BULK AMOUNT: 29.00 G	
22	ENRICHMENT: 11.74%	ISOTOPIC WEIGHT: 4. G	
23,24	IMPURITY .00% OF	MEASUREMENT CODE: F10	
25,26	SEAL NUMBER:	COEI NUMBER: 748	
27	ISOTOPIC A: .0006, B: .8651, C: .1174, D: .0149, E: .0020		

RESULTS

711/54/FS5301	NM VALUE: 366.00 G,	BULK VALUE: 2471.00 G
711/54/SC5301	NM VALUE: 4.00 G,	BULK VALUE: 29.00 G

TRANSACTION OK? (Y...YES, N...NO)

be recorded in each transaction record. DYMAC does this; however, at the current stage of development, audit trails can only be generated off-line.

To help assure the quality of the data it collects, DYMAC does two things: 1) it performs extensive diagnostics on user inputs, and (2) it minimizes the input required of user personnel by using on-line instruments and drawing on standardized information pre-coded into the computer data files. Diagnostic checks are performed on all input data. Each response typed in at the terminal is checked for the correct number of characters and for proper alphanumeric format. Many entries are then compared with valid contents of corresponding files. For example, a technician may respond with "G253" for glovebox 253, when asked for an item's new location. After checking the syntax of the response, the computer checks its validity by searching a file of the facility's location designators. The computer next searches the inventory file to see if an inventory record for that DYMAC name exists. If it does not, the operator is not allowed to continue. This check will detect a typing error, a mis-labeling, or an improper transaction that has previously been made.

Searches are also made of the instrument file to confirm the identity of the instrument used in the transaction, and searches the standards file to validate the standards used in the daily accuracy and precision checks of the NDA instrument used. If any of these diagnostic errors are found, the result is displayed on the process operator's terminal, so that he can take corrective action.

In addition to detecting errors, DYMAC tries to minimize the opportunities to make them. Whenever it is possible to let the instrument provide the input, or when the computer can generate or transfer data, this is done in preference to allowing human input. Some instrument measurement results are automatically read by the system and diagnostics are performed on the data to ensure its integrity and to guarantee that the transmission has been error-free. To provide the computer with the pre-coded information, each process in the facility has been analyzed to determine material flow and measurement points. For each step in the process, the computer has been pre-coded to know whether the item's name is changing, whether it is to be divided to form new items, or combined with another item. It also knows what type of material is involved, what verification is needed, what calculations to perform with the measured data, and whether completion of a process step indicates that a material balance can be drawn.

All this standardized information is stored in computer data files. When a technician identifies the process step he has just completed, the system accesses the appropriate file to furnish a large part of the transaction data. It only asks for human intervention when the information cannot be pre-coded.

The DYMAC measurement control program uses two kinds of checks to assure proper instrument performance. An accuracy check is made four times per week to verify that no changes have occurred in instrument response to working standards. Precision checks are made weekly for changes in reproducibility, and to detect non-random fluctuations in counting instruments that may indicate electronic problems. The data generated by these checks are transmitted to the computer for checks against control limits.

The data are stored in instrument history files for additional use, such as limit-of-error calculations. The control limits used are a 95% confidence level warning limit, and a 99% confidence level as an action limit. If an instrument check exceeds the action limit, or exceeds the warning limit twice sequentially, the computer does not allow the instrument to be used for accountability measurements until the instrument's performance has been brought back within the limits.

The type of performance check used depends on the instrument being tested. DYMAC currently treats balances and counting instruments somewhat differently. The accuracy check for balances requires the measurement of three standard weights that cover the normal operating range of the balance. A t-test compares the difference between the measured and standard values, to ensure that the response is consistent with previous observations and to determine possible bias terms. Precision checks consist of replicate measurements of each standard weight to estimate standard deviations for each level. These new standard deviations are then compared with the past 15 weeks polled standard deviation, using an F-test to monitor changes in balance reproducibility.

Counting instruments also use a t-test to check accuracy. In this case, a plutonium sample is used, and the instrument's actual response is compared with its expected response. Precision checks consist of two different tests that use the same set of 15 replicate measurements. The reduced chi-square test compares the counting variance estimate with a variance estimate based on replication. The replicate data are then tested for randomness, using a mean-square successive-difference test that can detect long-term trends or rapid oscillations that might otherwise go unnoticed.

There are three levels of responsibility for seeing that Safeguards procedures are followed. The unit process operator controls the entry of data, but there are only certain entries that he can make or change, and these are controlled by the computer program. His supervisor, at the MBA level, monitors the material balance of his area, and periodically takes a physical inventory to verify the balance. The supervisor cannot make changes in the data. If a discrepancy is found at any level, a change has to be requested of the Nuclear Materials Officer, who is the custodian at the station level. He is the only person authorized to make corrective changes at any place in the database.

Accountability personnel regularly assess the inventory information to determine whether Safeguards criteria are being met. They examine the balance of material that remains in an area after a batch is processed to ensure that no SNM has been diverted (see Fig. 3). On detecting an anomaly, an investigation is initiated. Such a system constitutes a deterrent to covert nuclear materials diversion by facility personnel. The improved timeliness and sensitivity also complements the facility's physical security system.

The Safeguards task facing the plant operator is that of guarding against diversion by a comparatively small number of people who have some degree of access to the material. Although the conspirators may be very knowledgeable and may have cooperation within their group, they do not have the cooperation of plant management. The SNM accounting system was designed to be of help to the plant operator in his safeguarding effort.

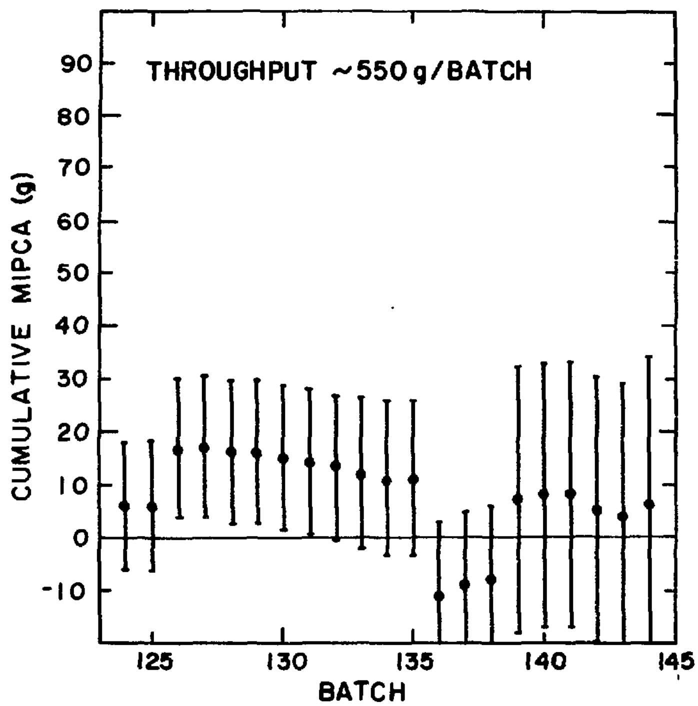

Fig. 3 A cumulative sum chart for the dynamic material balances of a unit process.

The accuracy of the database is strongly supported by the automatic features of the measurement control program and the error prevention code. Attempts to insert data that are too incorrect, or move material to illogical places, are discovered and flagged, and the diverter, even if he knew how, does not have access to the computer program to disable it. The in-transit monitor would discover the diversion if it occurred during transit. Loss at the unit process level could be discovered on any of three occasions: (1) by exceeding alarm limits on the current inventory, (2) at closure of the mini-balance around the process, and (3) at station cleanout. Periodic physical audits of material going into and out of process equipment provide a relatively frequent opportunity to discover a diversion.

The IAEA's position is quite different from that of the operator. First, the Agency is concerned with a diversion by the plant operator. Second, the Agency is in a hostile environment, dependent on its own capabilities, if the plant operator attempts to divert. While the DYMAC system is a major component of the US National Safeguards System, it also provides practical experience for assessing the potential for the compatability of advanced systems with international verification requirements.

The goals of the DYMAC system are to demonstrate the reliability and operational feasibility of NDA instrumentation in a production environment, to generate inventory data efficiently and accurately, to be sensitive to detection of missing material, and to be compatible with production control and quality assurance in a cost-effective manner. As DYMAC meets these goals, it will demonstrate the feasibility of applying its techniques to other processing environments.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #14: NUCLEAR MATERIALS ACCOUNTING AND CONTROL IN POWER REACTOR FACILITIES

SPEAKER: Dr. John Foley

Los Alamos Scientific Laboratory
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Friday, May 30, 1980
9:30 a.m.

BIOGRAPHY

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Present Duties: Research technology transfer, training in international safeguards.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #14: NUCLEAR MATERIALS ACCOUNTING AND CONTROL IN POWER REACTOR FACILITIES

SPEAKER: William A. Higinbotham

Brookhaven National Laboratory
Upton, New York USA

Friday, May 30, 1980
9:30 a.m.

BIOGRAPHY

See Session #13

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #14: NUCLEAR MATERIALS ACCOUNTING AND CONTROL IN POWER REACTOR FACILITIES

The basic features of nuclear fuel accounting and control in present day power reactors are considered. Emphasis is placed on identifying those points that could be sensitive targets for diversion or theft attempts.

After the session, participants will be able to

1. Describe basic fuel characteristics in major types of power reactors (light-water reactor, heavy-water reactor, gas-cooled graphite reactor).

2. Describe typical fuel quantities (fresh, in-core, spent) at the various reactors as a function of rated power.

3. Describe movement of fuel within the facility and basic fuel management practices.

4. Describe basic fuel accounting and inventory verification procedures for a reactor facility.

5. Describe certain reactor safeguards aids including seals, TV surveillance, and remote-power monitors.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION 14: NUCLEAR MATERIALS ACCOUNTING AND CONTROL IN POWER REACTOR FACILITIES

John E. Foley
Los Alamos Scientific Laboratory

I. CHARACTERISTICS OF NUCLEAR POWER STATIONS

Most of the world's inventory of plutonium is contained in the spent fuel assemblies that reside in the spent fuel ponds of nuclear power stations. Because reprocessing of these spent fuel assemblies is occurring at a very low rate and because away-from-reactor storage has not yet occurred to any significant extent, the world's inventory of plutonium will by necessity remain at nuclear power stations for many years into the future. Thus, the nuclear power station is of significant nuclear safeguards interest.

In this paper I discuss nuclear safeguards at nuclear power stations. The major emphasis is on the off-load refueled light-water cooled power reactors (LWR) because they are found in the greatest numbers in the world; however, some discussion is given to the on-line refueled heavy-water moderated and cooled reactor (HWR).

The discussion in this paper focuses on the single facility--the nuclear power station with its inventories of fresh fuel assemblies, in-core fuel assemblies, and spent fuel assemblies. Other facilities in the fuel cycle, such as fuel fabrication, fuel reprocessing, etc., are not considered.

The nuclear power station has several characteristics that are unique in the nuclear fuel cycle. Included are:

1. The nuclear material is almost always found in discrete, encapsulated units (called fuel assemblies) and it remains in the same physical form during its entire residence time at the power station. It arrives at the power station in the form of fuel assemblies, it resides in the reactor core as fuel assemblies, and it is stored in the spent fuel pond as fuel assemblies. The integrity of the assemblies is maintained. Fuel assemblies are rarely disassembled at nuclear power stations; however, this may change in the future and this will introduce new safeguards problems. At all other facilities in the nuclear fuel cycle--except the away-from-reactor storage pond--the nuclear material can change both physical and chemical form.
2. The nuclear power station is the only facility in the entire fuel cycle where large quantities of fissile materials (^{235}U and ^{239}Pu) are consumed and produced. Nuclear material is not conserved. A schematic representation of a nuclear power station is given in Fig. 1. The ultimate result of this consumption and production of fissile material is, of course, the generation of electrical energy.

Because the integrity of the fuel assemblies is maintained and because the nuclear material content of the fuel assemblies is not conserved, safeguarding at nuclear power station is primarily done by item accountability, containment, and surveillance.

II. CHARACTERISTICS OF "TYPICAL" NUCLEAR POWER STATIONS

The nuclear material at nuclear power stations can be grouped as (see Fig. 2):

1. Fresh Fuel
2. In-Core Fuel
3. Spent Fuel.

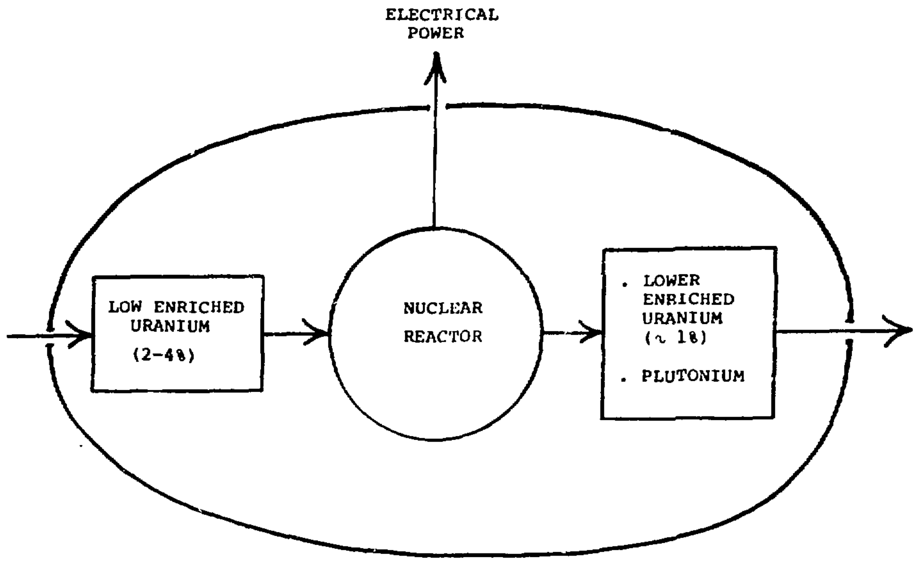

Fig. 1.
Schematic representation of a nuclear power station.

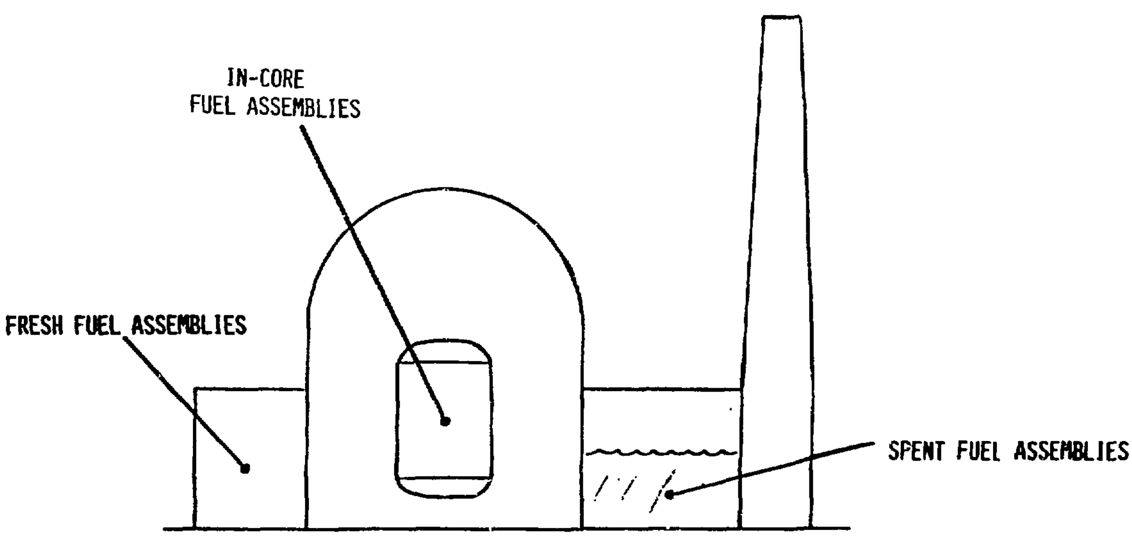

Fig. 2.
Locations of nuclear fuel at LWR power stations.

The amount of nuclear material in the power station depends on the reactor type and the reactor power level, the operating history of the station. Estimates of the nuclear material flow for "typical" light-water cooled reactors and heavy-water reactors are given in Table I.

TABLE I

TYPICAL POWER REACTOR CHARACTERISTICS[1]

Typical PWR (1000 MWe)

Off-load refueling	1 year interval
Fuel enrichment	2-4%
Core inventory	∿ 200 fuel assemblies (100 000 kg)
Reload	∿ 65 fuel assemblies
Spent fuel	∿ 65 fuel assemblies
Pu production	∿ 200 kg/year
Pu content spent fuel	∿ 3 kg/assembly

Typical BWR (1000 MWe)

Off-load refueling	1 year interval
Fuel enrichment	2-3%
Core inventory	∿ 750 fuel assemblies (140 000 kg)
Reload	∿ 190 fuel assemblies
Spent fuel	∿ 190 fuel assemblies
Pu production	∿ 200 kg/year
Pu content spent fuel	∿ 1 kg/assembly

Typical HWR (500 MWe)

On-line refueling	8 fuel bundles/day
Fuel enrichment	natural uranium (0.72%)
Core inventory	4680 fuel bundles (390 pressure tubes x 12 fuel bundles per pressure tube) 92 000 kg
Reload	on-line ∿2500 fuel bundles/year
Pu production	∿ 190 kg/year
Pu content spent fuel	∿ 0.04 kg/bundle

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[1] Adapted from references 1, 2, and 3.

The characteristics of the pressurized water reactor (PWR) that are listed in Table I correspond to a typical 1000 MWe station that operates on a once-through fuel cycle. The reactor is refueled off-load once a year; that is, the reactor is shut down for refueling. About one-third of the core (approximately 65 fuel assemblies) is replaced during the refueling. A fuel assembly for this reactor is shown in Fig. 3. The PWR fuel assembly typically consists of a 15x15 fuel rod array and weighs about 500 kg. Each fuel assembly has a unique serial number engraved on the top plate for identification. The uranium in the fuel is enriched to 2 to 4 percent.

The characteristics of the boiling water reactor (BWR) listed in Table I also correspond to a 1000 MWe plant operating on a once-through fuel cycle. This reactor is refueled off-load once a year

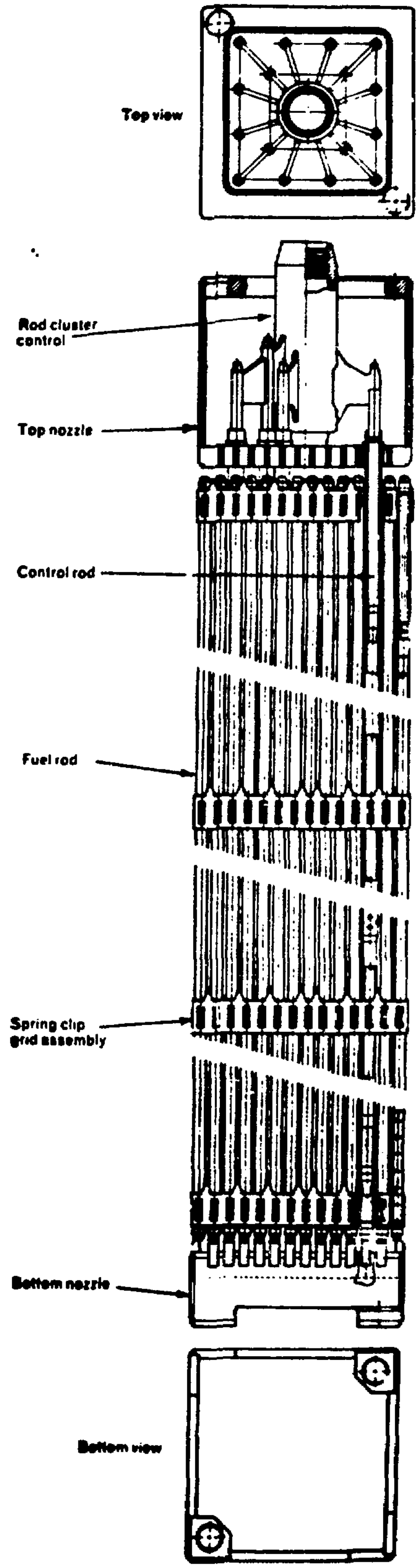

Fig. 3.
PWR fuel assembly (from Ref. 4).

during which about one-fourth of the core (or approximately 190 fuel assemblies) is replaced. The fuel assemblies typically are in an 8x8 fuel rod array and weight about 200 kg each (see Fig. 4). Each fuel assembly has a unique serial number for identification. The uranium in the fuel is enriched to 2 to 3 percent.

In both of these light-water reactors the fuel in the reactor is inaccessible during periods of operation. The top of the reactor pressure vessel must be removed before the refueling can take place. The fuel assemblies at a light-water reactor are basically stationary during most of the year.

The characteristics of the heavy-water moderated and cooled reactor listed in Table I correspond to a 500 MWe unit, characterized by the CANDU Pickering Generating Station. This reactor is refueled on-line; that is, refueling is done while the reactor is running. The reactor contains nearly 4700 fuel bundles (see Fig. 5). About eight fuel bundles are replaced each day

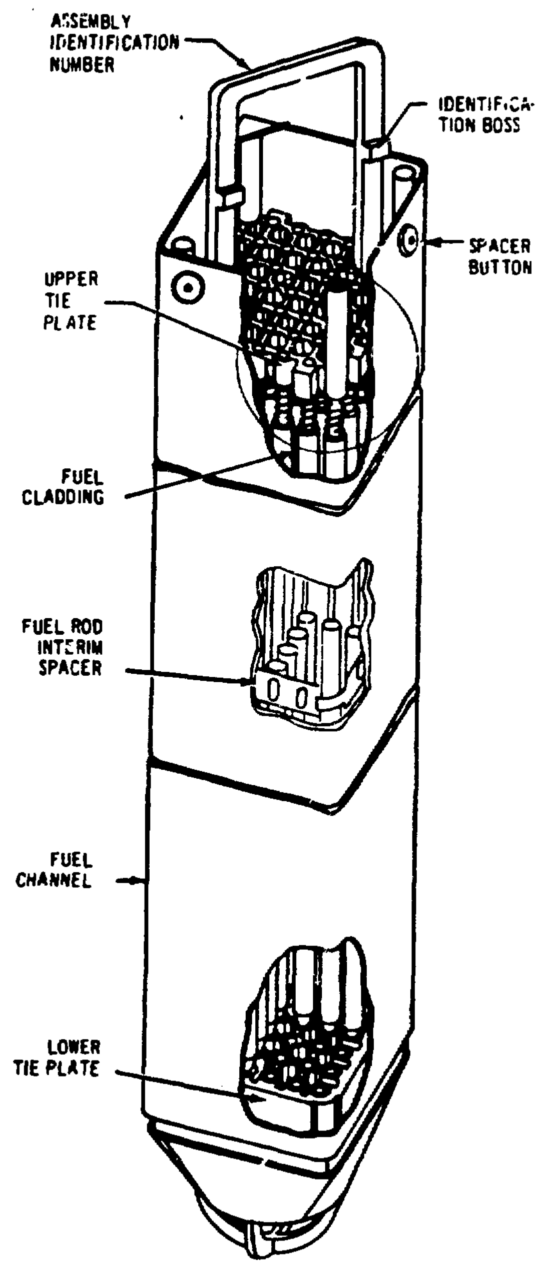

Fig. 4.
BWR fuel assembly (from Ref. 4).

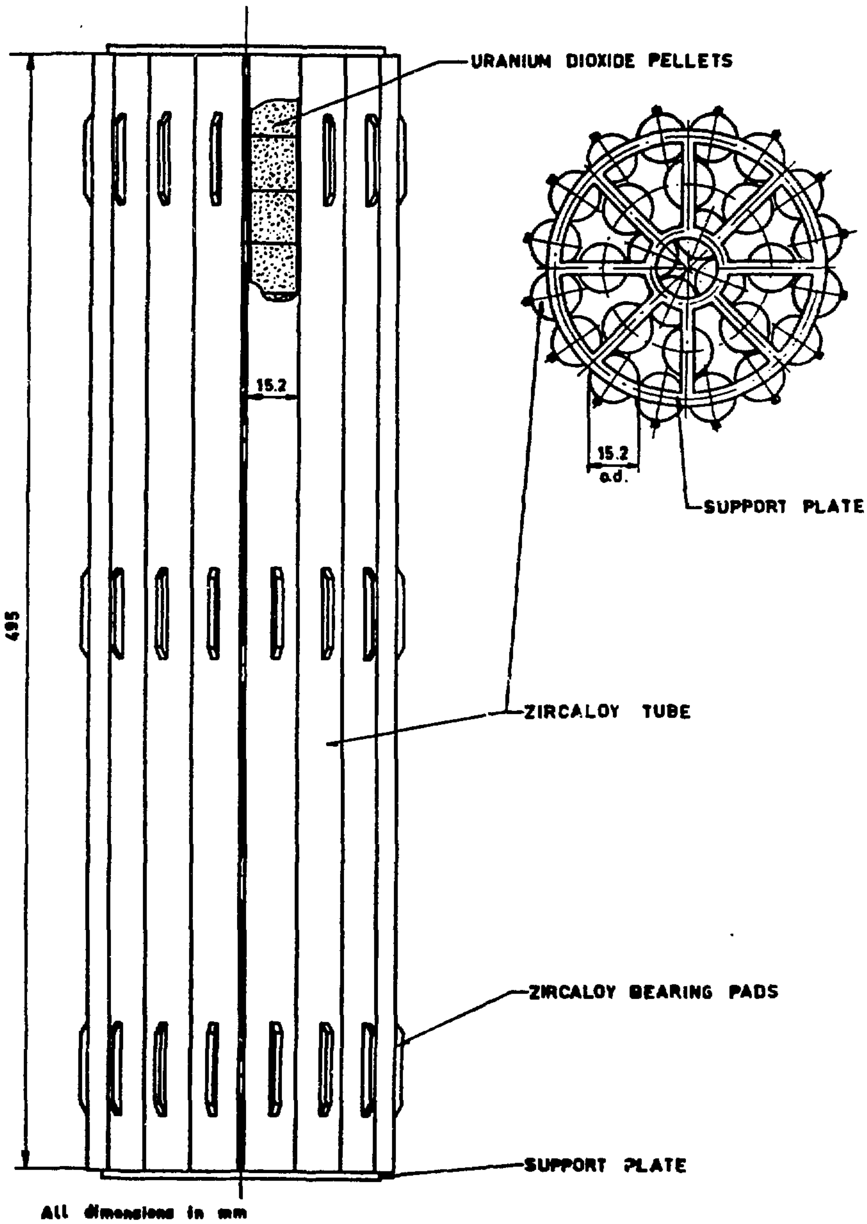

Fig. 5.
HWR fuel bundle (from Ref. 3).

while the reactor is operating at full power. Each fuel bundle weighs about 20 kg. All of the fuel bundles are essentially identical. The uranium contained in the fuel bundles is natural uranium.

III. "TYPICAL" FUEL INVENTORIES AT NUCLEAR POWER STATIONS

My estimates of typical fuel assembly inventories for the three types of nuclear power stations are shown in Table II. The PWR has the smallest number of fuel assemblies in the inventory and the HWR has the largest. The typical spent fuel pond is designed to hold spent fuel assemblies from several years of refueling.

Because the "back end" of the fuel cycle is not developing rapidly many spent fuel ponds throughout the world are being reconfigured to hold more spent fuel assemblies. Thus the number of spent fuel assemblies remaining at the spent fuel ponds of nuclear power stations is increasing.

Because of the large throughput of fuel bundles in the HWR the number of items in the spent fuel pond is very large. About 10 000 spent fuel bundles will accumulate at a single 500 MWe power station in 4 to 5 years.

TABLE II

TYPICAL FUEL INVENTORIES AT NUCLEAR POWER STATIONS

	Number of Fuel Assemblies/Bundles		
Reactor Type	Fresh Fuel Storage	In-Core	Spent Fuel Storage
PWR	$\sim$ 75	200	few hundred
BWR	$\sim$ 200	750	several hundred
HWR	several hundred	4680	several thousands

IV. SAFEGUARDING NUCLEAR POWER STATIONS

Because the nuclear material at nuclear power stations is in discrete units in the form of fuel assemblies (or bundles) safeguarding is most commonly done by supervision of items,[5] which is also called item accountability.[6,7] Safeguarding in this manner circumvents the problems that would exist if safeguarding were done by verification of masses and isotopic content of the fuel assemblies. At the nuclear power station an "item" is generally a single fuel assembly or fuel bundle. The safeguards at a power station should be capable of detecting the unauthorized removal of a single item; that is, a single fuel element (Figs. 3 and 4) at an LWR or a single fuel bundle (Fig. 5) at an HWR.

Safeguarding by item accountability requires that the safeguarding authorities, which are both the national authority (including EURATOM) and the international authority (IAEA), be able to verify the identity of the items. This is generally done by item counting and identification of serial numbers. Seals and surveillance cameras (both movie and video) are used to complement item accountability to reduce the effort required during physical inventory verification.

A. National System of Accounting for and Control of Nuclear Materials

The starting point for safeguards under the IAEA is the State system of accounting for and control of all nuclear material subject to safeguards. For the nuclear power stations in the State, the national regulatory authority must establish the appropriate nuclear materials accounting and control regulations; establish a national information system for the collection, organization, and analysis of the safeguards information; and verify compliance with the regulations through inspections. For those States under NPT safeguards, the elements of the national system are given in INFCIRC/153 (Ref. 8).

The elements of the national system should include the following:

1. The operators of the power station must keep accurate records of: (1) the receipt at the station of fresh fuel assemblies; (2) internal transfers of assemblies from the fresh-fuel storage to the reactor core, and from the reactor core to the spent-fuel pond; and (3) shipments from the station of spent-fuel assemblies (and fresh-fuel assemblies that do not satisfy quality control specifications). The operators must send a report to the national information system detailing these fuel assembly movements in a timely manner (1 to 2 weeks).
2. The operators of the power station must provide periodic (perhaps at six month intervals) nuclear material status reports that account for the nuclear material consumed (uranium) and produced (plutonium). The consumption and production of nuclear material is calculated from the operating history of the station.
3. Inspectors from the regulatory authority must periodically visit the station to assure that the operators are complying with the national regulations.

In the United States, the national regulations are given in Title 10 of the US Code of Federal Regulations[9] and are implemented through the Nuclear Regulatory Commission.[10]

B. IAEA Requirements

In applying international safeguards to a nuclear power station, the IAEA begins with information about the station provided by the State in the IAEA's Design Information Questionnaire (DIQ). The purpose of the DIQ is to convince the IAEA that the station can be effectively safeguarded. From the information in the DIQ, the IAEA develops the Facility Attachment that details the specific safeguard activities that will be applied at the plant. This Facility Attachment defines the Material Balance Areas and the key measuring points, establishes the records that must be kept and the reporting requirements, defines the containment and surveillance techniques, and establishes inspection activities.

Examples of responses to the DIQ for an LWR power station are given in references 11 and 12.

C. Safeguarding Activities at Light-Water Reactors

The items (fuel assemblies) being safeguarded are located at three places in the LWR power station: fresh fuel storage, reactor vessel, and spent fuel storage. In all of these locations the items can be visually observed: the items in both the fresh fuel storage and the spent fuel storage can be identified and counted at any time; those items inside the reactor vessel are accessible only when the reactor vessel is open.

Since it is not practical to have inspectors at power stations continuously, seals and surveillance equipment are used to establish the continuity of the safeguards during the time intervals between inspections. For example, seals are used above the reactor vessel to verify that the fuel assemblies inside the reactor vessel have not been removed. Movie and video cameras are used to verify that the movements of assemblies in the spent fuel pond agree with the stations records.

Because all of the fuel assemblies are visually accessible at least once a year, it is possible to reestablish the inventory by item inspection (serial numbers) if there is a loss of continuity of the safeguards because of a failure of the surveillance equipment.

Typical safeguards activities that take place at an LWR are shown in Fig. 6. The inventory of fresh fuel assemblies is verified by identification of the serial numbers that are stamped on the top of the fuel assemblies. The fresh fuel assemblies are either verified while they are in their storage containers

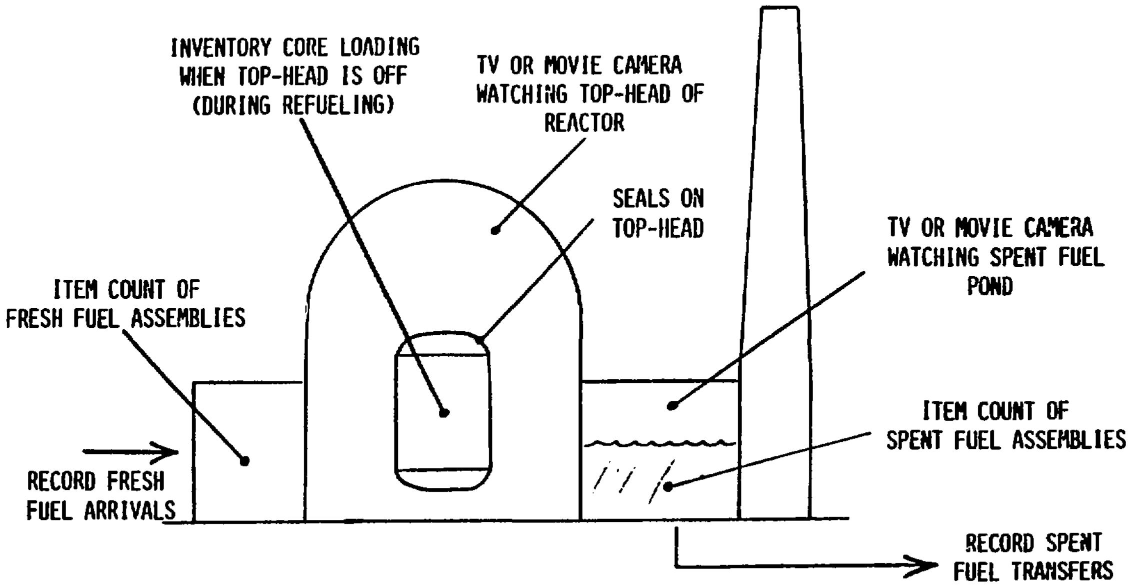

Fig. 6.
Safeguards activities at an LWR power station.

(where they are dry) or in the storage pool just prior to being transferred to the reactor building for insertion into the reactor. Inspection of serial numbers of assemblies in the storage pool where they are located under several meters of water requires the use of an optical magnifier, such as binoculars.

During refueling when the reactor vessel is open, the in-core inventory is verified by counting and identification of serial numbers. The in-core fuel assemblies are located under about 10 meters of water and binoculars are required for the identification of the serial numbers of these fuel assemblies. After the refueling is complete and the reactor vessel is closed, seals are applied to the shielding blocks above the reactor vessel.[5,13] Since these seals must be broken prior to the removal of the top of the reactor vessel, they provide verification that the in-core inventory was not changed during the absence of the inspector. Also, a surveillance camera is installed inside the reactor vessel as a backup to the seals. Because removal of both the shielding blocks above the reactor vessel and the head of the reactor vessel takes considerable time (days), this surveillance camera only needs to take frames infrequently; as few as 400 frames in a period of six months[5] will ensure that an unreported opening of the reactor vessel will be detected.

As the spent fuel assemblies are removed from the reactor vessel and are transferred to the storage pond, a map giving the grid location of each assembly is made. In the storage pond, as in the reactor vessel, the assemblies are located under about 10 meters of water. During a physical inventory the inspector verifies with binoculars that the spent fuel assemblies are in their proper locations. Also, surveillance cameras (movie or video) are installed inside the spent fuel bay to record the movement of the crane, fuel assemblies, spent fuel cask, and the entrance and exit doors. The surveillance pictures are reviewed by the inspector to verify that the station's record of activities since the past inspection are correct. The surveillance cameras ensure the authenticity of the assemblies in the spent fuel pond and reduce the effort required to complete the inspection. If the surveillance equipment fails, the integrity of the pond must be reestablished by visual verification of all the assemblies.

The IAEA typically makes several inspections per year at nuclear power stations. They make an annual physical inventory and two or three interim routine inspections.[6,7] The objective of the annual physical inventory verification is to establish that the station's inventory is correct. The inventory verification generally occurs at the end of the annual refueling, but before the top of the reactor vessel is replaced so that the inventory of items inside the reactor vessel can also be verified.

Typical activities that occur during inspections at an LWR are shown in Table III, which is an abbreviated version of a table in Ref. 6.

Inspectors also collect data from the operators of the station that are related to calculated burnup, nuclear consumption and production which will be useful for safeguards of reprocessing plants.[7] This data is not used in the safeguarding of the nuclear power station, but is used at a later time for safeguarding the spent fuel at the reprocessing plant.

TABLE III

SAFEGUARDING ACTIVITIES AT A LIGHT-WATER REACTION

Event	Task
After receipt of fresh fuel (one visit)	Removal of seals at assemblies and identification, records audit, check of seal at vessel, routine identification of irradiated assemblies, maintenance of camera.
After shut-down but before re-fueling	Removal of seal at vessel; identification and counting of fuel at reactor vessel, fresh fuel storage and spent fuel storage; records audit; maintenance of camera.
After re-fueling but before start-up	Identification and counting of fuel vessel and storages, fixing of seal to vessel, and maintenance of camera, records audit.
Intermediate inspections (three visits)	Identification and counting of fuel at storages, check of seal at vessel, records audit, maintenance of camera.
After completion of shipment of irradiated fuel	Identification and counting of fuel at storages, check of seal at vessel, records audit, isotopic data acquisition; maintenance of camera.

D. Safeguarding Activities of Heavy-Water Reactors

The HWR power station, characterized by the CANDU reactor, differs from the LWR power station in many ways and the safeguards measures that are applied at the HWR station are necessarily different.[14] Figure 7 gives a schematic of the flow of the fuel bundles in this type of reactor. The fuel bundles are inserted and removed from the reactor by fueling machines. The fuel bundles are not accessible while they are in the core of the reactor.

After removal from the reactor the spent fuel bundles are transferred to storage trays in the spent fuel pond by a transfer elevator where they are stored in the horizontal position. As the storage trays are filled they are stacked in baskets. Except for the fuel bundles in the tray at the top of each basket, the fuel bundles are not easily accessible.

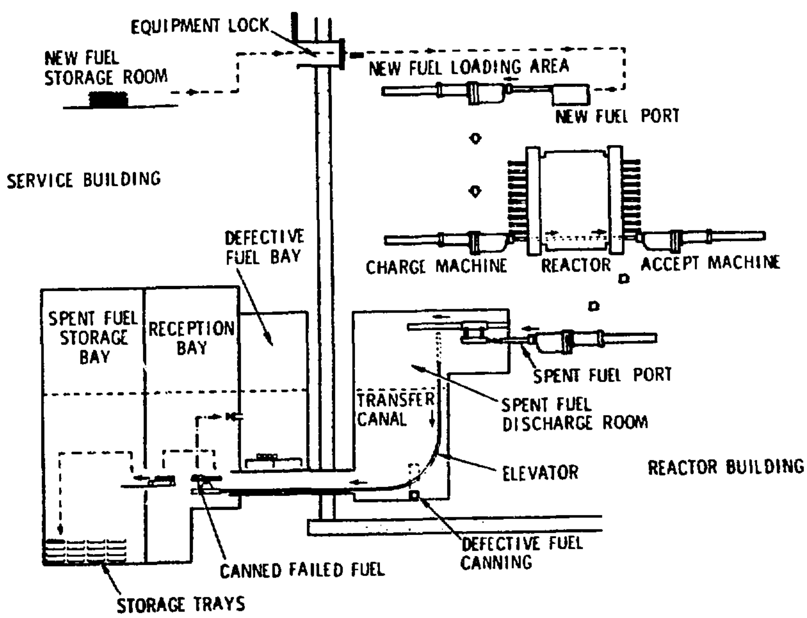

Fig. 7.
Fuel bundle movement path at an HWR power station (from Ref. 15).

The problem of safeguarding an HWR is characterized by keeping track of a very large number of items that are primarily inaccessible. A physical inventory verification of bundles inside the reactor is not possible because the fuel bundles are not visible inside the pressure tubes. Verification of the bundles in the spent fuel pond is difficult because most of the bundles cannot be seen. Only the fresh fuel bundles are accessible.

Safeguarding HWR fuel bundles is done by item counting. Because most of the fuel bundles are inaccessible it is necessary to use surveillance equipment to keep control of the items. For example, a fuel bundle counter[14] records the number of bundles that enter the spent fuel bay from the reactor and video surveillance cameras provide evidence that no fuel bundles have been removed from the spent fuel bay. Seals are placed on the lids of the baskets that hold the spent fuel bundles to reduce the verification effort.

Because it is not possible to keep track of the large number of fuel bundles after they arrive at the spent fuel pond, it is necessary to rely on the surveillance equipment to ensure the integrity of the inventory in the pond.

V. UNIQUE FUEL ASSEMBLY SEAL

A significant simplification in the safeguards activities at the LWR power station would be achieved if a unique seal could be attached to each fuel assembly at the fuel fabrication facility that would remain on the assembly until it is dissolved at the reprocessing plant.[16] The fuel assemblies would thus have seals during their entire stay at the nuclear power station.

The unique seal would be designed so that any attempt to disassemble the fuel assembly would destroy the seal, or would indicate that tampering had occurred. This type of seal would not only provide a unique identification for the assembly, but would also guarantee the authenticity and the integrity of the assembly because attempts to transfer the seal to another assembly or to fabricate a duplicate seal would be detected.

Several laboratories throughout the world are working on unique seals, but no seal has yet attained significant use. The major concern about such a seal is that it might interfere with the safe operation of the nuclear power station.[13]

VI. NUCLEAR MATERIAL BALANCE

Currently very few nondestructive assay (NDA) measurements are made of the nuclear material in the fuel assemblies at nuclear power stations. Those that are made are mainly qualitative (for example, to indicate that the spent fuel assemblies are in fact highly radioactive, as they should be). The NDA measurements are complementary to the item accountability and the containment and surveillance techniques that are used at nuclear power stations.

Considerable effort is being expended throughout the world today to develop quantitative NDA methods for spent fuel assay.[17] For example, high resolution gamma-ray techniques are being applied to the determination of the burnup of spent fuel.

These more quantitative measurements of burnup and, eventually, the NDA measurement of both plutonium and uranium fissile content will possibly provide the necessary input values for the materials accountability systems for the remaining parts of the fuel cycle; i.e., the reprocessing plant.

However, contrary to what might be expected, such quantitative measurements in themselves do not provide information that can be used for safeguarding the nuclear power station. The results of measurements of the plutonium content of the spent fuel assemblies will be of no use in safeguarding the nuclear power station unless these measured results are compared with the plutonium production expected from the operating history of the station. For these quantitative measurements of burnup or plutonium content to be useful in safeguarding the nuclear power station it will be necessary to develop, in parallel with the NDA developments, the techniques to allow the inspector to independently establish the expected burnup and plutonium production from the operating history of the nuclear power station. Safeguarding of the station is then done by finding agreement between the measured burnup (or measured plutonium content) and the expected value determined from the operating history.

ACKNOWLEDGEMENT

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #15: SAFEGUARDING OF NUCLEAR RESEARCH FACILITIES

SPEAKER: Ed R. Johnson

E. R. Johnson & Associates
Reston, Virginia USA

Friday, May 30, 1980
10:45 a.m.

BIOGRAPHY

Education: B.S. in Chemistry from Bowling Green State University (1951)

Present Position: President of E. R. Johnson Associates, Inc., a nuclear energy technical and management consulting organization. Mr. Johnson is also Chairman of Nuclear Audit and Testing Company. In these capacities he has been involved in a number of technical and economic studies concerning various steps of the nuclear fuel cycle, radioactive waste management, transportation of radioactive materials, safeguards and quality assurance.

Past Positions: Mr. Johnson was Vice President of Nuclear Fuel Services, Inc., during the period 1957-1967. Here he was responsible for negotiation and administration of contracts for nuclear fuel fabrication and reprocessing. He was involved in the planning, start-up, process development and licensing of the NFS reprocessing plant. Prior to 1960, Mr. Johnson organized and directed the nuclear material control, licensing and technical programs of the NFS plant at Erwin, Tennessee--which was one of the first commercial nuclear fuel plants in the U.S. Mr. Johnson was associated with the National Lead Company during the period 1952-1957 at the AEC plant at Fernald, Ohio.

Other Activities: Member and former chairman of the Institute of Nuclear Materials Management. Member of the American Chemical Society, the American Institute of Chemical Engineers, the American Society for Metals, the American Nuclear Society, and the Atomic Industrial Forum.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #15: SAFEGUARDING OF NUCLEAR RESEARCH FACILITIES

The basic features of nuclear research facilities and nuclear material accounting and control therein are considered. Emphasis is placed on identifying points of high sensitivity to diversion or theft of material in nuclear research facilities.

After the session, participants will be able to

1. Describe the important features of major research reactor types (TRIGA, MTR, Swimming Pool), subcritical research assemblies, and prototype or pilot fuels technology and handling facilities.

2. Describe the criteria for identifying sensitive diversion or theft points within these facilities.

3. Describe nuclear material accounting procedures applicable to such facilities.

4. Identify certain applicable safeguards aids such as seals and basic NDA verification techniques.

SESSION 15: SAFEGUARDING OF NUCLEAR RESEARCH FACILITIES

L. K. Hurst and E. R. Johnson
E. R. Johnson Assoc., Inc.

I. INTRODUCTION

Nuclear research laboratories are uniquely designed to provide a suitable environment in which experimental nuclear studies may be conducted or demonstrations may be made in the basic and applied disciplines. Such work may encompass any or all fields of physical and biological sciences. For example, the multipurpose national laboratories in the U.S.A. have conducted research investigations aimed at furthering both the knowledge and understanding of the laws of nature and for advancing the development, use, and control of nuclear energy. Their programs are concerned with investigations in the fields of high- and low-energy physics, chemistry, biology, metallurgy, chemical engineering, reactor engineering, radiological physics, solid state physics, and electronics. Other laboratories may be limited in their commitments such that the studies they perform are dedicated to a few products or single disciplines.

In many nuclear research laboratories specialized reactors are available to the research staffs to provide the atomic radiation needed for their experimental purposes. Some examples of the ways in which reactors are used include material activation for qualitative and quantitative analyses, for radiation chemistry effects and for nuclear geochemistry studies; nuclear fuel and components exposure to neutron and incident radiation for irradiation damage studies; and reactor lattice studies. These examples are by no means exhaustive but are intended only to illustrate the wide range of investigations which can be conducted with the aid of such facilities.

II. REACTOR TYPES

The types of reactors in use today which provide the environments or facilities appropriate for these research and educational pursuits include sub-critical assemblies, teaching reactors, research reactors and materials testing reactors.

A. Sub-Critical Assemblies

Sub-critical assemblies are low-neutron-flux, essentially zero-power, pilot plants in which physics concepts are tested or new parameters are learned. Each assembly is a model of a desired critical assembly, insofar as the quantities and distribution of materials which will affect the neutron reaction. No attempt is made to provide structural components comparable to an operating power reactor design; in fact the design of the sub-critical assembly is such that variations to the loadings of fuel and neutron reflecting and absorbing materials can be made relatively easily.

B. Teaching Reactors

Teaching reactors are small, low-flux reactors designed for use as aids in reactor physics educational courses and to provide limited radioisotope production and research requirements. Most of these are compact, self-contained units available from several suppliers and ready for immediate installation.

C. Research Reactors

Research reactors are versatile sources of nuclear radiation for experimental purposes. They operate at low- to medium-flux levels. Experiments are conducted in the reactor and in the path of neutron beams coming through ports in the reactor shielding.

There are two basic design differences in the research reactors in common use today. In one case the reactor is suspended in an open pool of water which serves as the neutron moderator, coolant and radiation shield. Considerable flexibility to the researcher is available by this arrangement since the fuel and experimental apparatus can easily be shifted and positioned.

In the second case the reactor core is fixed in a grid arrangement within a closed tank. The moderator can be beryllium, graphite, light water or heavy water or a combination of two or more. Most often the coolant is light water, but heavy water, air or inert gas may be employed. Shielding is generally provided by dense concrete and lead. Tank type reactors frequently are supplied with heat removal equipment which permits higher power operation and correspondingly higher neutron flux than generally available in pool type reactors.

D. Materials Test Reactors

Materials testing reactors are high-flux, large tank-type facilities used to test the performance of reactor fuel, neutron moderating and absorbing materials, coolants, structural material and equipment components under irradiation. Dedicated to obtaining data essential for new (usually power) reactor designs, they normally carry a large and diverse test load. They usually are equipped with in-reactor test loops in which irradiation experiments are conducted under temperature, pressure and flow conditions expected or known to occur in power reactor operations.

III. REACTOR DESIGNS

There are many different reactor designs that have been prepared and more are possible. Several reasons exist for this multiplicity. First, the designer has a wide choice of materials, fuel, coolant, etc., which may differ appreciably from one design to another. Second, as stated earlier, there is a broad spectrum of reactor uses. And third, reactor designers often have different ideas as to the best way of designing a reactor for each given purpose.

Basically, there are five major parts of a nuclear reactor. They are:

- A core of fuel elements;
- The moderator, a material in and around the core to aid the fission process by slowing down the neutrons;

- Control rods, devices which regulate the number of free neutrons and thereby set the rate of fission;
- The coolant, a fluid to remove the heat generated in the core and elsewhere; and,
- Radiation shielding.

A. Reactor Fuel

Of these components, the one important to this discussion is the reactor fuel coupled with the fact that the essential ingredient of fuel is fissionable material, that is, a substance that readily undergoes fission when struck by neutrons. The only substance found in nature which is fissionable by slow neutrons is uranium-235, an isotope of uranium constituting only 0.71% of uranium as it is found normally. Essentially all the rest of the natural substance is uranium-238. This latter isotope is known as fertile material because it can be converted into fissionable material--namely, plutonium-- when it is irradiated by neutrons. Another fissionable substance, uranium-233, can be produced by neutron irradiation of the element thorium. There are thus three materials which can serve as fuel for reactors, (uranium-235, plutonium and uranium-233) one naturally occurring, and two produced by transmutation.

Reactor fuel always contains a mixture of fissionable material with fertile material. When the fuel is used during reactor operation, atoms of the fissionable material are expended, although at the same time some new fissionable atoms are formed from the fertile material. The ratio of expended to newly formed atoms depends upon the design of the reactor; however, in all cases except in the breeder concept, reactors operate with a net loss of fissionable material.

The percentage of fissionable atoms in the fuel mixture is important because it can affect the physical size of the reactor. The higher the percentage, the more compact the reactor can be. Some reactors are fueled with natural uranium which, as we noted earlier, contains less than one percent of fissionable atoms.

Other reactors are designed to use fuel mixtures ranging in fissionable atom concentrations from a few percent up to about ninety percent.

The size of the reactor may also be influenced by the physical form of the fuel. Generally, the fuel is solid. It may be metallic uranium, an alloy of uranium or plutonium or both with one or more other metals, a ceramic such as an oxide or carbide or a cermet. The solid fuel is shaped into plates, pellets or pins and grouped into units called fuel elements. The number and length of these elements depends upon the size, purpose and design of the reactor; a core may have as few as ten or twenty fuel elements or may require several hundred.

As a protective measure all fuel elements intended for use in a reactor are clad in an inert material to prevent direct contact between the fuel material and the other reactor components. The clad also serves as part or all of the structure of the fuel element. The elements are normally held together in a fixed cubic or pseudo-cylindric pattern by means of a grid structure. Steel, zirconium alloys and aluminum are commonly used cladding and structural materials.

B. TRIGA Reactors

In the U.S.A., the General Atomic Company, based in San Diego, California, has developed a family of TRIGA reactors designed to meet the diverse needs of academic institutions, industrial centers and certain research laboratories. Installed in pools these reactors operate at steady-state power levels up to 2 MW(t), with natural convection core cooling.(1) With forced flow cooling, steady-state power levels in the range of 3 to 15 MW(t) are possible. The TRIGA can also be modified to operate as a pulsing reactor with peak power levels to 22,000 MW(t).

Thus, in this one family are examples of pool type reactors which can be used for training, basic research, isotope production and performing reactor kinetics studies and transient testing of power reactor fuel. More than 60 TRIGA's are in operation; however, the General Atomic Company is not the only supplier of pool type reactors. For example, a competitive product is the Slowpoke-2 reactor, designed and built by Atomic Energy of Canada, Limited.

C. D_2O Moderated Research Reactors

Tank type reactors are not currently marketed as a finished product. Design and construction of these are more custom based, that is the buyer usually stipulates the number and type of special features desired.

One example of the custom-built tank type is the heavy water moderated reactor designed and constructed at the Argonne National Laboratory. The basic design was first used for CP-3 and later modified for CP-5. The latter was fueled with about 18 fuel assemblies, each fabricated from two concentric tubes of coextruded aluminum clad uranium--aluminum alloy. The CP-5 design, later modified to use plate-type fuel, was employed in the construction of several reactors installed at U.S. universities.

The CP-5 design has numerous facilities for research programs and services. A pneumatic transfer system is intended for production and measurement of isotopes with very short lives by rapidly transferring a capsule (rabbit) containing the specimen from the core to a counting room. A graphite tray located in the graphite reflector below the tank provides for large-scale isotope production. A removable, large, graphite column extending from the reactor tank through the concrete shielding provides a source of well-thermalized neutrons either in a spacious shielded area or extracted in a beam for external experiments. Each vertical face has one or more 6- to 8-inch horizontal-beam ports extending through the concrete shield to the graphite reflector or through it to the core to permit the extraction of core radiations, or the insertion of equipment for in-reactor studies. The top face too is penetrated by ports. Not only do these ports exist for insertion and withdrawal of fuel elements but they are also used for insertion of samples or research equipment into thimbles which are located in the centers of the tubular fuel. Surrounding the core, more thimbles exist in both the moderator and the reflector regions for these same purposes.

D. Test Reactors

Among the continuing requirements of the nuclear reactor industry is the need for materials and components that can withstand extremely high temperatures and radiation. To establish the capability of materials and components or to develop materials for such environments, materials test reactors have been utilized in this and other countries for several years. These reactors like their smaller prototypes, the tank type research reactors, are custom designed. Facilities which have been constructed and operated in the U.S. include the Materials Testing Reactor (MTR), the Engineering Test Reactor (ETR), and the Advanced Test Reactor (ATR) at the National Reactor Testing Station in Idaho, the Westinghouse Electric Corporation Test Reactor in Pennsylvania and the General Electric Company Test Reactor (GETR) in California.

These reactors have basic similarities but size, power level and core components may be markedly different. The GETR, for example, was the smallest of this series and it operated at about 30 MW(t). Compare this to the ATR, the largest, which operates around 250 MW(t). The others operated in between. However, since the basic structural designs are similar, only the GETR design[2] will be examined extensively.

The GETR core was contained in an aluminum pressure vessel which was submerged in a water pool that served both as a reflector and a large flexible irradiation zone. The vessel, or tank, was a 2-ft-diam cylinder which was centered on the bottom of a 9-ft-diam pool. Pressurized, light water was used for cooling and moderation in the core, and un-pressurized, light water was used in the pool.

The core consisted of a matrix of 37 positions each 3 by 3 inches. This position matrix essentially was a 5 by 5 cross-section array with the center three rows in each direction extended to seven positions by adding one position to each row's extremities. Each of the positions were filled with either fuel, control rods, filler pieces or experimental devices.

Fuel normally occupied twenty positions; these were all twelve positions outside the 5 by 5 array and eight of the nine centermost 3 by 3 array. The center position normally did not contain fuel; however, depending upon the in-core and pool experiment loadings, the number and location of the fuel elements were adjustable to provide an adequate reactivity balance. Except for six positions in which control rods were positioned to operate permanently, all positions not occupied by fuel were occupied by beryllium or aluminum filler pieces. Peripheral reflector pieces made of aluminum and beryllium machined to fill the spaces between the curved pressure vessel walls and the fuel-element matrix surrounded the array to provide neutron reflection and round the core into a cylinder.

Filler pieces and peripheral reflector pieces were provided with cavities in which experiment capsules could be positioned to utilize the core's high flux. Experiment space was also available in the pool for capsules, hydraulic shuttle, trail cable and a hairpin loop.

E. <u>Zero Power Reactors</u>

The subcritical assembly reactor type is also custom designed and constructed. One such facility, so built, is the Zero Power Reactor III (ZPR-III), originally designed and assembled for the Argonne National Laboratory at its Idaho, U.S.A., site. This machine was installed for the reactor physicists to conduct studies for the development of fast (epithermal neutron) reactor systems.

This facility and its three successors (the ZPR VI and ZPPR at the Argonne National Laboratory and the ZPR at Japan's Atomic Energy Research Institute) are constructed in the matrix form of two huge egg crates standing on edge and positioned face-to-face.

One of the halves is stationary. The other is movable; electric-motor powered, it moves horizontally on steel tracks away from or toward the stationary half. When the egg crates stand open, access to the two faces of the bisected assembly become available for loading, unloading or changing the core configuration. These matrices are hand-loaded with reflector or a combination of core, reflector, and structural materials in the form of blocks and thin plates stacked in drawers. When the core configuration and reflector blankets are complete, the two halves are closed for continuation of the reactor physics studies.

Materials used for the mock-ups in the ZPR's usually are metallic or ceramic plates and blocks. These are items carefully machined to stack well and to fit closely the boundaries of the matrix. Plates of uranium enriched in the isotope U-235 usually are not acquired with their enrichment at the nominal target value of a fast reactor conceptual design but more likely are at higher values. An adjustment of the enrichment may be accomplished by diluting the enriched fuel plates mechanically with shim plates made to the same size as the fuel but from natural uranium or from uranium depleted of its U-235 isotope. Of course, plutonium and uranium containing the isotope U-233, must be hermetically sealed in a suitable cladding material (usually stainless steel) to provide radiological health protection.

IV. REACTOR SERVICE AREAS

Most reactor buildings include storage areas and equipment maintenance and assembly facilities. Storage requirements typically involve at least three levels of concern. Sensitive and expensive equipment and samples may need protection from the curious or meddlesome person or from an environmental condition such as dust, humidity or even light. Locked storage areas with environmental controls sufficient to provide the prescribed levels of protection will most likely exist.

Irradiated specimens, hardware and fuel require shielding to protect persons in adjacent areas from penetrating radiation and may require cooling to reduce temperatures caused by gamma heating. For these purposes, the facilities which have reactors operating at low to medium flux will provide a pool or canal of water within the complex but probably in an area some distance away from the reactor, that is, in an area less coveted by research staff for placement of experiment equipment. The facilities which have reactors operating at high flux, such as the larger research reactors and the materials test reactors have no other choice than to have the canal adjacent to the reactor so that the extremely hot items are kept under the surface of the coolant continuously during discharge operations.

New fuel and specimens containing special nuclear material may need protection from environmental conditions, from the curious or meddlesome person, or from those intending diversion. Floor storage vaults or walk-in bank-type facilities usually serve these purposes.

Service laboratories also within reactor buildings provide space for equipment associated with the irradiation or test programs underway. In the research reactor facilities, the beam tubes which permit radiations to be extracted from the reactor frequently are fully utilized and the floor space around the reactor (usually the grade-level floor) becomes filled with experiment equipment. The equipment associated with in-reactor studies normally is located in less valuable space (from an experimenter's point of view) such as a basement or sub-basement level. Specialized laboratories for conducting radiochemical or radiobiological studies are sometimes within the reactor complex in rooms adjacent to the reactor room for ease and minimizing delay in transporting samples from the reactor to the study area.

V. RESEARCH LABORATORIES

Research staff conducting studies on specimens for or from operating research and test reactors are not always located within the reactor building complex. Instances where the programs are diverse and the staffs large require laboratories of a size exceeding the capabilities of a conventional reactor building to house them. Facilities for these situations are provided in out buildings, sometimes rambling structures contiguous with the reactor building, or located as distinct separate structures in an arrangement similar to a modern university campus.

One such separate structure was the totally contained fuel development laboratory at the Argonne National Laboratory. Originally designed and built to develop plutonium base fuels for both thermal and epithermal neutron reactors this facility was sufficiently flexible and well equipped to permit considerable research and production of prototype fuel elements.

Because plutonium is a hazardous material to work with, all operations are conducted in dry boxes. These are supplied with inert atmosphere to reduce the chance of fires and are interconnected to permit the passage of products, specimens and tools from one to the other without the need to use bagout devices. Also, the dry boxes are installed and equipped in a manner to permit access to the internal equipment from both sides. As a result, essentially the entire facility appears to have one continuous train of boxes.

Plutonium-based fuel elements are prepared much like their uranium predecessors in that alloys, ceramics and cermets may be used. The Argonne facility processed all of these and used pure metals or oxides as feed. No chemical purification or reduction steps were provided; dependence for the supply of feed products was placed upon other U.S.A. facilities. Alloying, casting, rolling, machining, canning and welding steps were employed to prepare metallic products; mixing, pressing, sintering, grinding, canning and welding steps were used for ceramics and cermets. Dependence for recovery of residues was placed upon other U.S.A. facilities also; however, a preliminary treatment of residues was accomplished by controlled oxidation of all skulls, flashings, chips, dust, rejects, etc., to acquire a product which would not spontaneously ignite during storage and shipment and which could be homogenized for sampling.

VI. SAFEGUARDS CRITERIA

It is important to appropriately protect special nuclear materials which are used in the peaceful application of atomic energy from theft, or from diversion for production of nuclear weapons. This protection of special nuclear materials is called "safeguards." It is comprised of three basic components; namely, the diligent control of and accounting for the materials involved, the physical protection of them and of the facilities in which they are contained, and surveillance and inspection. The application of these components must take into consideration at least four basic criteria which may influence surreptitious removal of materials from any premise by unauthorized persons. These include availability, attractiveness, capability of concealment, and transportability.

The principal objective of safeguards activities is to provide a timely warning of possible diversion or credible assurance that no diversion has occurred. The detection of a diversion can be achieved if the materials control and accountancy systems are adequate. The time required for converting stolen special nuclear materials into forms which can be used to produce nuclear explosives will depend on the degree of difficulty involved in effecting such conversion. Where extensive processing is necessary to convert them into nuclear explosives the better the opportunities are for obtaining a timely warning that a diversion has taken place.

A. Availability of Special Nuclear Materials for Diversion

With respect to the prospect of theft or diversion of special nuclear materials, an important objective of safeguards must be to prevent unauthorized persons from obtaining access to or possession of special nuclear materials especially when they are in forms readily convertible to nuclear explosives. Such persons will not likely have the same level of resources and technology readily available to them as would authorized persons. If they have to process stolen special nuclear materials to convert them into a form usable in explosives, the processing probably will provide a significant deterrent and probably will require much time to accomplish. Here the effective physical protection of nuclear materials in forms which are readily convertible into nuclear explosives or weapons is particularly important.

The principal vulnerability of the research facilities may be the relative accessibility of fairly large amounts of special nuclear material. These may occur as feed for fuel fabrication processes; as material in use during development, fabrication and storage of new fuel for reactors and test specimens for research programs; as material in use as fuel and test specimens in reactors; and as spent fuel and residues from fabrication and research activities in storage waiting for disposition.

B. Relative Attractiveness of Different Special Nuclear Materials for Diversion

A nuclear reactor must be fueled with fissionable materials, whether it is designed to be a research reactor or a test reactor. These fissionable materials used in nuclear fuels are always in combination with fertile materials in fresh fuel and are sometimes in combination with other fissionable materials in the spent fuel discharged from nuclear reactors. Table 6-1 sets forth the fissionable/fertile mixtures which are contained in the various reactor fuels, the fissionable/fertile mixtures which are contained in the corresponding spent fuel, and the methods available for recovery of the fissionable material component in each case.

Mixtures of U-233/U-238, and U-235/U-238 can be upgraded by enrichment processes to concentrate the fissile content to a level suitable for weapons use. The U-233 will separate more readily from U-238 than will U-235, but U-233 produced by the irradiation of thorium contains significant quantities of U-232. This isotope decays through a series of radioactive daughter products which will make the material dangerously radioactive, will contaminate the enriching equipment and thereby will require remote operation and maintenance of enrichment facility.

TABLE 6-1

TYPICAL NUCLEAR FUEL MATERIALS AND CORRESPONDING SPENT FUEL COMPOSITIONS AND METHODS OF FISSILE RECOVERY/CONCENTRATION

Fresh Fuel Materials		Spent Fuel	
Composition	Method of Fissile Recovery/Concentration	Composition	Method of Fissile Recovery
U-233/U-238	Enrichment[1]	U-233/U-238/Pu	Reprocessing[3,4]
Pu /U-238	Chemical Separation[2]	Pu /U-238	Reprocessing[3]
U-233/Th-232	Chemical Separation[2]	U-233/Th-232	Reprocessing[3]
Pu /Th-232	Chemical Separation[2]	Pu /Th-232/U-233	Reprocessing[3]
U-235/U-238	Enrichment[1]	U-235/U-238/Pu	Reprocessing[3,4]
U-235/Th-232	Chemical Separation[2]	U-235/Th-232/U-233	Reprocessing[3,4]

(1) Enrichment--processes for the physical separation of fissile (fissionable) uranium from non-fissile uranium.

(2) Chemical Separation--processes for the chemical separation of individual elements which are contained in unirradiated fuel mixtures (low to medium radioactivity levels are involved).

(3) Reprocessing--processes for the chemical separation of individual elements which are contained in irradiated fuel mixtures (high radioactivity levels are involved).

(4) Enrichment could be used after reprocessing is completed to concentrate fissile uranium content of the uranium product.

The other mixtures of fresh fuel materials can be readily separated by chemical processes in relatively simple facilities. As stated earlier, U-233 is more difficult to process because of the presence of U-232 daughters and of the need to employ remote operating and maintenance techniques. Plutonium too is more difficult to handle than U-235 because of the presence of Pu-241 and its decay to americium-241, thus requiring the use of some shielding in the chemical separation operations. The U-235 requires no special shielding or equipment.

The processing of spent fuel to recover contained fissile material is substantially more difficult than processing fresh fuel, due to the presence of highly radioactive fission products in the fuel. Fission products are formed in the fuel during use in the reactor and result from the fissioning of U-235, U-233 and plutonium. Therefore, such reprocessing must be conducted behind massive shielding in remotely operated facilities. However, when the fissionable/fertile materials have been separated from the fission products, such mixtures can be processed in much the same manner and with the same type of facilities described for the fresh fuel materials.

The processing of dilute mixtures of fissile materials in fertile materials involves the handling of correspondingly larger quantities of mixture than more concentrated mixtures in order to obtain the same quantity of fissile material. However, the overall difficulty in effecting separation from dilute mixtures is much greater for the enriching process than it is for chemical reprocessing, and is greater for reprocessing than it is for chemical separation of materials of lower radioactivity.

Based upon the above criteria, the relative difficulty of upgrading fissionable materials to a form suitable for weapons production is set forth in Table 6-2.

A number of different methods are available to qualitatively assess the diversion risk of materials in the various portions of the alternative fuel cycles. Investigators at Oak Ridge National

TABLE 6-2

QUALITATIVE RANKING OF EASE OF UPGRADING FISSIONABLE MATERIALS TO A FORM SUITABLE FOR USE IN WEAPONS PRODUCTION BY KEY ATTRIBUTES OF UPGRADING METHOD

Required Upgrading Method	Ranking[1] Capital Cost	Availability of Technology	Complexity of Technology	Availability of Process Equipment & Facilities
Enrichment--Shielded Facilities (U-233 from U-235 and U-238)	7	6	6	5
Enrichment--Unshielded Facilities (U-235 from U-238)	6	5	5	4
Reprocessing--Heavily Shielded Facilities (U-233, U-235 and Pu from FP)	5	4	4	3
Chemical Separation--Shielded Facilities, A[3] (U-233, U-235 and Pu from spiking agents)	4	3	3	3
Chemical Separation--Shielded Facilities, B[3] (U-233 processing)	3	2	2	2
Chemical Separation--Shielded Facilities, C[3] (Pu processing)	2	2	2	2
Chemical Separation--Unshielded Facilities (U-235 processing)	1	1	1	1

(1) Lowest ranking--easiest
Highest ranking--most difficult (see Reference 3)

(2) FP--fission products

(3) Shielded Facilities A--signifies less shielding than required for reprocessing facilities.
Shielded Facilities B--signifies less shielding than required for Shielded Facilities A.
Shielded Facilities C--signifies less shielding than required for Shielded Facilities B.

(4) Spiking agents--radioactive material intentionally added to mixture to make its handling by a prospective divertor more hazardous.

Laboratory, Argonne National Laboratory, Hanford Engineering Development Laboratory and Savannah River Laboratory performed an analysis of alternative fuel cycles for proliferation evaluation. The investigators[3] established two basic criteria of measuring proliferation risks associated with a fuel cycle, (1) the convertibility of the fissionable material involved at each step, which is a measure of the usefulness of the diverted material for weapons production; and (2) the radiation hazard associated with such step, which is a measure of the danger in handling the fissionable material if removed from the process as well as the danger involved in the alteration of a process step to effect the diverson of fissionable material. The qualitative rating given by these investigators to the convertibility of diverted material is shown in Table 6-3.

The qualitative rating given by these investigators to the radiation hazard associated with the various processing steps which are involved in a fuel cycle is shown in Table 6-4.

These qualitative methods of rating complement the ratings presented earlier in Tables 6-1 and 6-2. Together they establish a rationale for assessing the sensitivity of various inventories of special nuclear materials to diversion by predicting the effort necessary to prepare such materials for weapons usage, and to theft, to some extent, by establishing the relative ease with which the materials can be removed. Some inventories appear to be essentially fully protected from theft by v ue of extreme radioactivity associated with fission products which have formed during their use in research and test reactors; however, fuel in exponential and zero power assemblies and in low power teaching reactors seldom become sufficiently active to provide any protection.

C. Capability of Concealment of Special Nuclear Material

Many physical sizes, shapes and forms of special nuclear material appear in the inventories frequently on hand in research facilities. Discussed earlier are fuel assemblies used to power

TABLE 6-3

QUALITATIVE RATING OF CONVERTIBILITY OF FISSIONABLE MATERIAL FORMS

Rating Identification		Description of Material
Nonfissionable	--	material that cannot be used directly to make a weapon (such as natural and depleted uranium, and thorium).
a	--	material that requires a shielded isotope separation facility for upgrading to weapon quality (such as U-233 denatured with U-238).
b	--	material that requires an isotope separation facility (such as less than 20% U-235 in U-238).
c	--	highly radioactive material requiring remotely operated engineering equipment for chemically separating weapon material from impurities.
d	--	weapon material that can be separated from impurities in relatively simple facilities, or material that is in a form suitable for a weapon without additional treatment.

research and test reactors. These are usually made with 15 to 20 aluminum clad, uranium-aluminum alloy plates, each about 3 inches wide by 36 inches long, assembled into 36-inch-long units by brazing side plates to them. The plates are spaced to permit water to flow between. Top and bottom nozzles are attached for use during reactor insertion and removal, in controlling coolant flow, and for mechanical interface with reactor fuel core support plates. These extend the assembly to four or more feet in length.

Surreptitious removal of components of this size, while possible, would be difficult. Such capability is lost, or at least decreases appreciably, by the use of these in reactors. Removal

TABLE 6-4

ORNL/TM-6036 QUALITATIVE RATING OF RADIATON HAZARD ASSOCIATED WITH THE UNAUTHORIZED REMOVAL OF MATERIAL FROM OR MODIFICATIONS TO FUEL CYCLE FACILITIES

Radiation Hazard		Description of Hazard
High	--	radiation level equivalent to LD_{50} at 30 cm in a few minutes, nominally greater than 10,000 R/hr.
Medium	--	radiation level capable of producing harmful physiological effects in one day (10 to 10,000 R/hr).
Low	--	radiation level resulting in severe exposure in several days but insufficient to prevent fabrication of a weapon (less than 10 R/hr); such exposure could lead eventually to death.
Negligible	--	no harmful radiation effects from the material being handled.

LD_{50} -- represents the amount of radiation that would cause death to 50% of the persons exposed in a specified amount of time.

R/hr -- a unit of measure of the amount of radiation per hour which emanates from the radioactive material involved.

of irradiated fuel from the premises will usually require heavily shielded containers to protect the handlers from radiation.

Other inventories are more vulnerable. Feed stocks of plutonium and uranium metals or dry compounds, such as oxides, require very little space for containment of significant amounts. Similarly, the fuel designed for use in exponential and zero power assemblies may be undiluted and concealed in small packages such that a clandestine manner of removal might be successfully employed.

D. Relative Transportability of Special Nuclear Material for Diversion

Vulnerability of inventories of special nuclear materials in research facilities for reasons of transportability appear similar but not necessarily comparable to the vulnerability due to capability of concealment.

The difficulties discussed above which result in an incapability to satisfactorily conceal stolen special nuclear materials also provide a significant deterrent to transporting them in a manner believed suitable to persons who are authorized to possess them. Obviously, lead-filled casks used to shield highly radioactive fuel elements are transportable but are not easily so. Cranes, trucks, off-loaders and other specialized heavy-duty equipment which are necessary are neither convenient nor inconspicuous. Rapid transit, also a preference, is essentially missing.

Considering unirradiated materials, the smaller the package, the more easily transportable the commodity becomes. When materials are small enough not only does the transporter have the opportunity to hide the articles on himself or with other goods he also has the option to disguise them as something else.

VII. ACCOUNTING CONTROL

The methods employed for the control of special nuclear materials in research facilities differ in many respects from methods used in processing facilities. Generally the various research inventories have a very slow turnover. A researcher may have the same material for many months whereas at a processing plant the material flows through an operation, usually within a few days.

Generally, neither research nor development activities are routine, and routine confirmation of quantities of materials held by the research staffs may be very disruptive. When there are numerous and varied studies underway, a similar range of quantities and types of materials must be controlled. In manufacturing plants, typically there is a routine generation of material control information, and there are sampling points and measurements, established for production, quality and financial controls, which can and are used for special nuclear material control. Such control information is not available regularly in research facilities.

A. Accountancy for Special Nuclear Material

Regardless that measurements and movements of special nuclear materials in research facilities are non-routine, the standard accepted practices of accountancy are applied.[4] Essentially, here as in other nuclear establishments, the elements of "inventory control" accounting found in other industries are employed. The non- routine characteristics only prevent simplified applications of those elements.

Fundamentally, the first step in establishing special nuclear material control is to develop a management approved policy within which all control measures will be implemented and then prescribe internal accounting methods that will provide satisfactory control of material. The decisions made and the methods adopted are incorporated in written procedures which become the guide for all material control activity. These written procedures set forth the policies of how management requirements are to be met; they establish consistency in the methods to be employed in accounting for material flow within the plant; and they serve as the basis for auditing.

The basic objective is the development of a system which will provide the most efficient and effective compliance with the management needs for material quantity information. The balances reported indicate the total amounts of special nuclear materials for which the research organization is responsible; only those activities which cause increases or decreases to the balances have meaning during report compilation. Material balances are affected mostly by external transactions, that is, those transactions concerned with receipts of material from other installations or shipments of material to other installations. Internal activity becomes important to the total balance only in those instances where a material balance is changed due to approved write offs, consumption of material during use or production as a result of reactor operations.

1. Central Control Ledger. An overall control ledger is usually established by using the same format as that desired in the balance report. This is not difficult because the balance report is normally closely aligned with external activities and these are recorded on material transfer documents. Several advantages accrue by using the balance report format for ledger purposes; namely, the preparation of balance reports becomes a simple task of transcription and a firm control of external document flow is automatically established.

The format needs relatively few additions to make the control ledger self-balancing. Control accounts for the various types of materials on hand must be established, as well as a reconciliation account, to establish balance between the overall control ledger and those subsidiary ledgers in use.

Posting to the control ledger is a matter of choice as to how and when it should be accomplished and what documents are considered proper posting media. However, when those choices have been made, appropriate disciplinary measures must be applied to assure that consistent practices are employed. The control ledger will not be useful as a "control" device for either document flow or its more primary use unless the posting is accomplished on a regular periodic basis. Normally, a regulated use of forms will make it possible to record all information applicable to the control ledger on not more than three or four forms. The material transfer document is used to record each external activity; internal activities affecting the control ledger are recorded on receiving reports and on inventory adjustment reports, that is, reports which document changes due to consumption or production.

2. Item Control Records. The accounting activities for internal control records in research facilities often become complex. This is not because the accounting methods are different or complex but rather because the necessary information is frequently difficult to obtain. Consequently the decision about what figures are valid for record purposes sometimes may be based on theory rather than accurate measurements.

The problems of research facilities include the need to internally control special nuclear materials which may vary in size from infinitesimal amounts to substantial quantities and vary in status and condition from that which can be measured directly to that which can only be determined by estimate. Frequently, the types and quantities of material vary so widely that the application of statistical methods to determined values becomes impractical. Fortunately, the larger segments of the inventories, which are more significant from a safeguards interest, are also usually subject to statistical evaluation. However, regardless of the problems faced in accounting, an adequate control must be maintained to make meaningful the balance report figures as well as to have credible records for use by the scientific staffs.

One of the more effective methods of maintaining an acceptable level of internal accounting control for special nuclear material committed to research programs is to itemize the material and set up an individual accounting record for each item. Depending upon the volume of items and transactions to the items, either electronic data processing or manual systems may be employed to maintain the historical records for them.

Materials handling groups independent of the central accounting function and responsible for controlling materials within designated areas are perhaps better able to provide input data to the system. Each area should maintain its own record of materials within the area. These same material control personnel should provide receipt inspection, verification of quality and quantity, and initiation of receiving reports for any material received into their designated area from outside sources and provide inter-area and intra-area transaction reports for material flow between scientists or projects.

Upon receipt of material an item card is prepared. This card contains a complete description of the material, including type, assay, and gross and net weights and a numerical identification number. Any transaction reports, that is, the receiving report and any transfer reports affecting this item, are posted to this card to reflect to whom and when the material is issued and where it is located. If only a part of the material is issued a new card is prepared to record the part removed; the item number is extended to indicate that a division of the material has occurred and to provide traceability to its source.

Every transfer of custodianship should be documented by internal transfer documents. The control exercised by area material control groups assure the timely initiation and completion of these forms. Both the consignee and consignor sign the document in agreement that the transaction is correct and complete, and the material control person signs to indicate that the material and values stated agree with the control records.

Periodic reporting by areas to the central accounting group starts the process of checking and balancing the records before the overall material balance report is prepared. Areas first must be certain that all activity prior to the closing date is posted and the item card system balances to their summary account. When these area reports are received by the central accounting group, comparisons are made of the area totals with the control ledger for agreement and posting balance. Upon completion of this study and reconciliation made of any existing differences, the control ledgers are considered to represent the values of material in the work areas.

3. Inventories. Verifying the existence of the entire stock of special nuclear material within a research facility is one of the more difficult problems which the control group faces.

A complete facility shutdown and a methodically directed examination of all holdings would be preferable to the control group, however, such interruption to research activities could well waste or destroy extensive and expensive effort. Consequently, these verification activities are scheduled to permit the scientific efforts to proceed in as uninterrupted a fashion as is possible. Generally an inventory is planned for a period when research activity is known to be low, although any activity using large amounts of material or generating large amounts of scrap must have routine inventories made on a periodic (say monthly) basis.

Otherwise quarterly or semi-annual inventories (the frequency depends upon the quantity held by the research facility) are conducted by following procedures generally acceptable in other industries. Where there is a property record identifying each discrete item, an acceptable inventory method is to employ a list of items prepared in advance by the central accounting group. Members of the audit team will complete their copy of the list by entering quantities observed by physical verification methods. Upon completion of the inventory the lists are returned to the accounting group for reconciliation of the accounts. Differences are investigated for possible error and for cause if the differences are real.

B. Accountability

Special nuclear material control is complicated by the conditions inherent in the operation of a diversified research facility. The nuclear material inventory can include items which vary in quantity from a few milligrams in a sample used for isotopic mass determinations to several thousand kilograms such as that in use in exponential experiments. The application of rigid controls may be more necessary for a small specimen representing the major portion of an available supply than is necessary for non-proliferation safeguards control on larger but less valuable material.

Material may be used in an extensive series of investigations in a study of part of the complete fuel element cycle from preparation of feed materials for the fabrication processes, through fabrication, use and final reprocessing. Accurate and complete material balances may be impossible to obtain for several months.

Such circumstances demand that close attention be given to the control of special nuclear material at all stages of the studies undertaken. But also these circumstances require that an application of accountability be made which differs from that in other types of facilities. In a processing plant or a nuclear power plant, the person accountable for special nuclear materials normally is the plant manager or plant superintendent, that is, the last person down the organization chain who can accept undivided responsibility for the material. In research facilities this principle prevails too, however, here undivided responsibility most often is vested in an individual scientist or at worst, in a group leader, where several persons are engaged in a single study. Consequently, accountability for special nuclear material in use in research establishments is passed through the organization chain to each individual who has hands-on responsibility for the study to which "his" special nuclear material is committed.

VIII. SAFEGUARD AIDS

This section of this paper is not intended to be a review of all measurement methods and other techniques which may be used in a safeguards system nor is it suggested that all major work which has developed these and other techniques has been compiled and evaluated. Rather it is intended to identify several destructive and non-destructive aids which may and frequently are employed in research facilities to verify the quantities and qualities of the special nuclear materials in their possession or to provide tamper detection capability for materials in storage.

A. Destructive Analyses

For adequate accounting of special nuclear materials, accurate estimates must be made. When these materials are in reasonably homogeneous form, chemical and isotopic analyses usually will satisfactorily characterize them, so these methods usually become the preferred means through which the data are acquired. These methods include but are not necessarily limited to assays accomplished fluorophotometrically, spectrographically, chromatographically, gravimetrically and spectrometrically.

B. Passive Non-Destructive Assays

Not all of the time is it advantageous or possible to fully characterize special nuclear material inventories. Such measurements announced above appear reasonable for metals and alloys, stable oxides and salts, and solutions; however, any of these materials can become difficult and costly to analyze when they are in shapes or items specific for a research program or become distributed into many small pieces of a large inventory.(5) A typical example is the fuel plates for one ZPR where there exist several thousands plates of uranium-plutonium alloy varying in length between four and eight inches by two inches wide by about one-fourth inch thick.

Upon receipt, and for inventory re-verification, these plates were individually examined by a spectrometer with an automatic scanner using a Ge(Li) detector, to measure the gamma rays in the 380-keV region emitted by the Pu-239 isotope.(6) The spectrometer was periodically calibrated with plates of known plutonium content. Agreement within reasonable expectations was obtained between the gamma assay and vendor chemistry results. This method is one of several passive nondestructive methods which are available for specific situations. It is known to be passive because it is dependent upon spontaneously generated nuclear radiations from an isotope to determine its presence quantitatively.

Another gamma-ray spectrometer utilizes a NaI(Tl) detector. While the resolution of this instrument is less than the Ge(Li) detector it is favored for scanning plates, pins, etc., containing U-235 because the crystal can be larger and can be shaped to see more surface. This spectrometer measures the gamma rays in the 185-keV region of the disintegration spectrum emitted by the U-235 isotope.

A recent study by LASL suggests that absorption-edge densitometry may be applicable to a number of materials frequently found in research facilities.(7) The current status of this instrument method is not known in time for commenting on its utility. However, based upon the conclusions drawn by LASL staff, it is a relatively simple, versatile, accurate, and nearly matrix-independent method for measuring special nuclear material. It would appear that its application for receipt inspection of plate type fuel for research reactors will be particularly valuable.

C. Active Non-Destructive Assays

Several techniques show promise for measuring the residual special nuclear material in spent fuel from reactors. One of these, studied by the Oak Ridge National Laboratory, uses an external source of interrogating neutrons to induce fissions in the Pu-239 and U-235 isotopes and measures the prompt neutrons from these fissions.(8) Several devices using active scanning methods, both neutron-neutron and neutron-gamma reactions, have been employed in major fuel fabrication facilities to routinely measure fresh fuel rods fabricated for light water power reactors.(9) These are especially useful where there is a large volume of one fuel rod design but their application to varied materials in research facilities has not so far appeared practical.

D. Security Seals

Most research facilities have found the use of security seals beneficial for purposes of reducing the handling and re-measuring of some parts of their special nuclear material holdings. Particularly for materials in storage, the use of seals reduces the verification activity needed for substantiating the contents of vessels sealed immediately after their contents are verified.[10]

Two seals which have had most common usage are those known as Type E Seals and Pressure Sensitive Paper Seals. Both have tamper indicating capability but both apparently have been compromised in test cases.

Other seals which are considered more reliable presently have delay problems associated with determining whether they have been compromised. Field verifiability has not been fully developed for these, therefore their usage has been limited.

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(10) Sesar Sastre, et al, "Use of Security Seals for Safeguards," Ibid.

PHOTOGRAPHS

(1) TRIGA Mark II at Johannes Gutenberg University, Courtesy of the General Atomic Company.

(2) TRIGA-ACPR at Japan Atomic Energy Research Institute, Courtesy of the General Atomic Company.

(3) 14MW Core, Romania Institute for Nuclear Technologies, Courtesy of the General Atomic Company.

(4) Oak Ridge Research Reactor Pool, Courtesy of Oak Ridge National Laboratory.

(5) CP-5 Research Reactor, Courtesy of Argonne National Laboratory.

(6) The GETR Core Matrix, Courtesy of the General Electric Company.

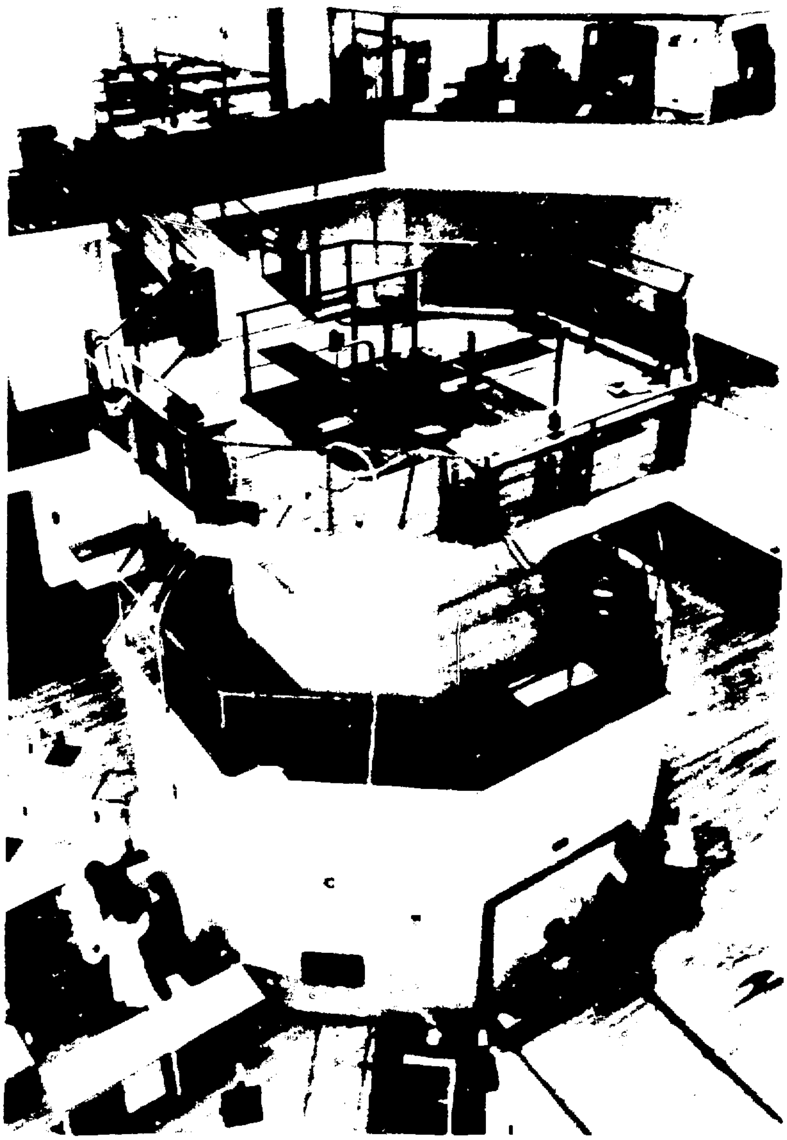
(7) Cutaway of the GETR with In-Core Test Assembly, Courtesy of the General Electric Company.

(8) ZPP-VI with Halves Separated, Courtesy of Argonne National Laboratory.

(9) Loading ZPPR, Courtesy of Argonne National Laboratory.

(10) Plutonium Fuel Fabrication Facility, Courtesy of Argonne National Laboratory.

(11) Remote Operated Hot Laboratory, Courtesy of Argonne National Laboratory.



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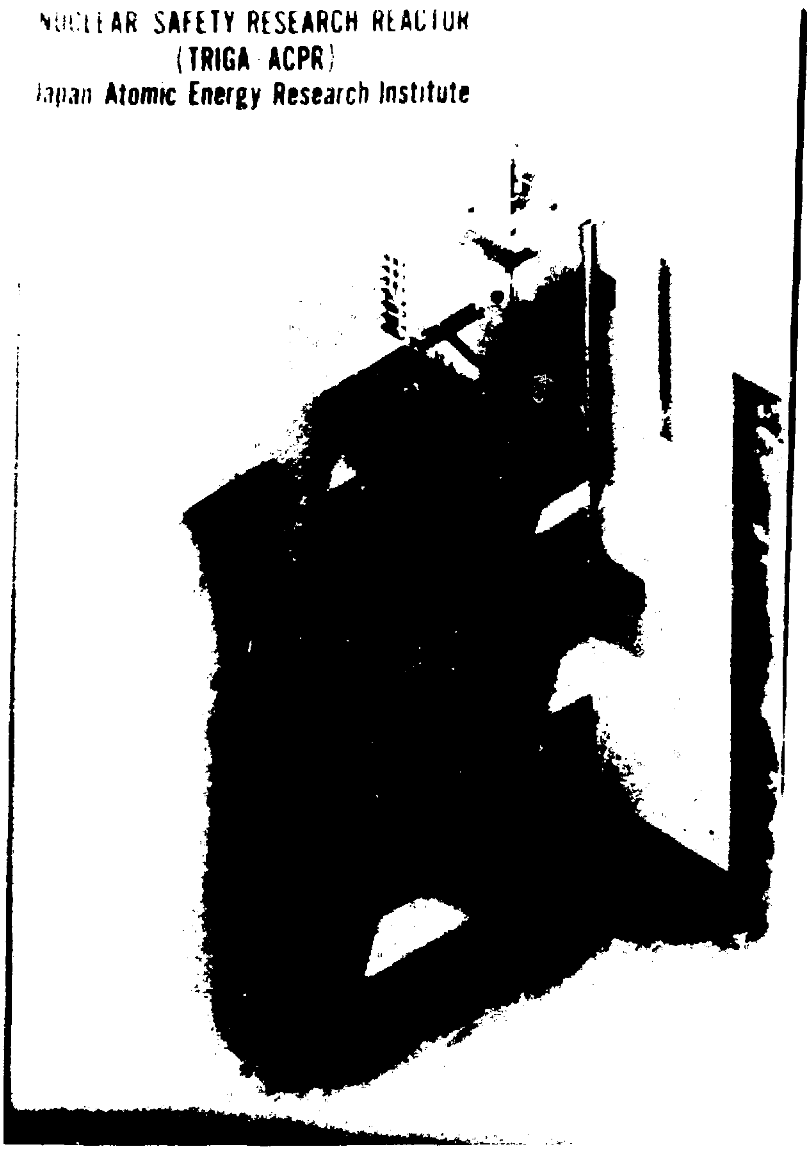

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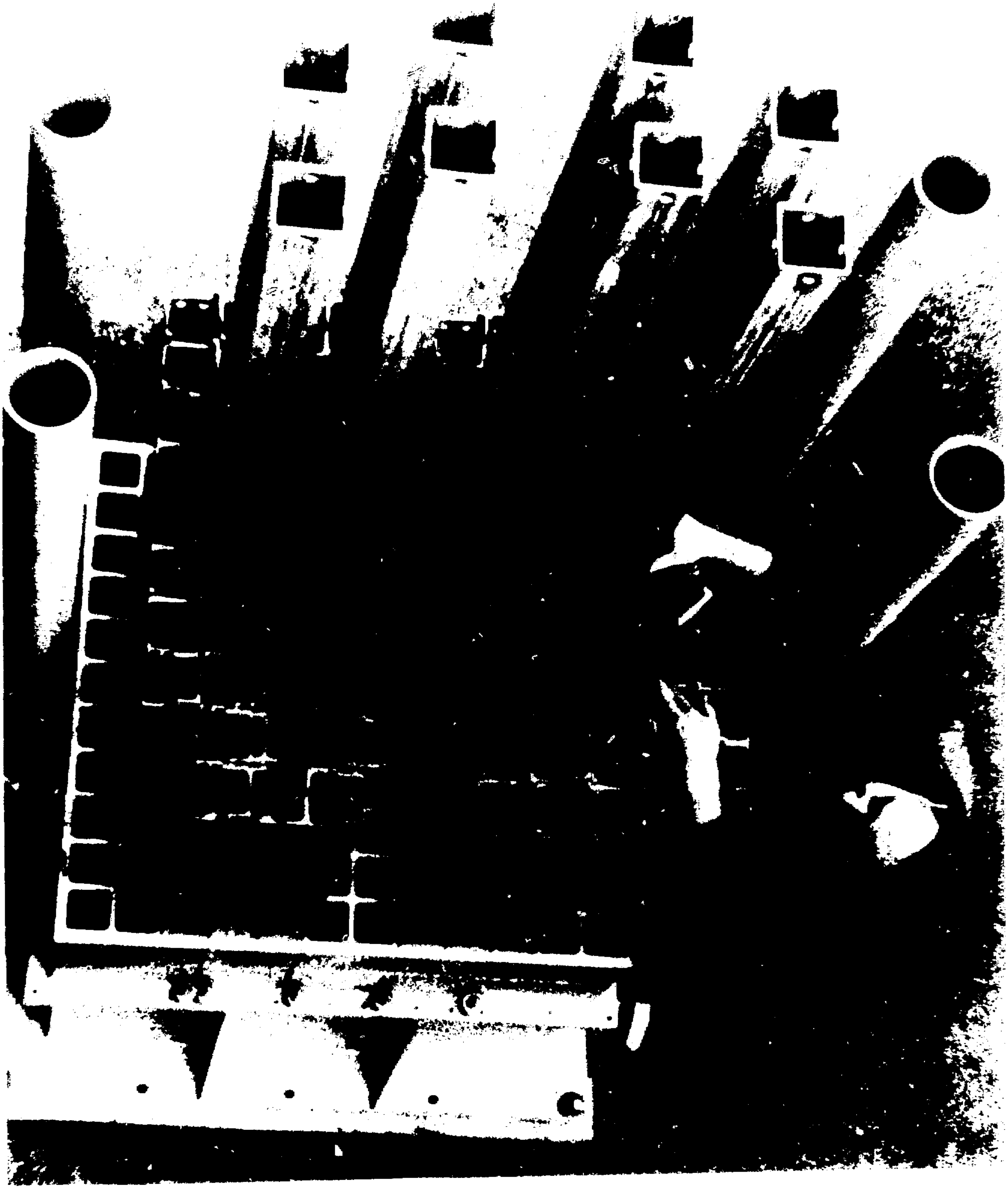

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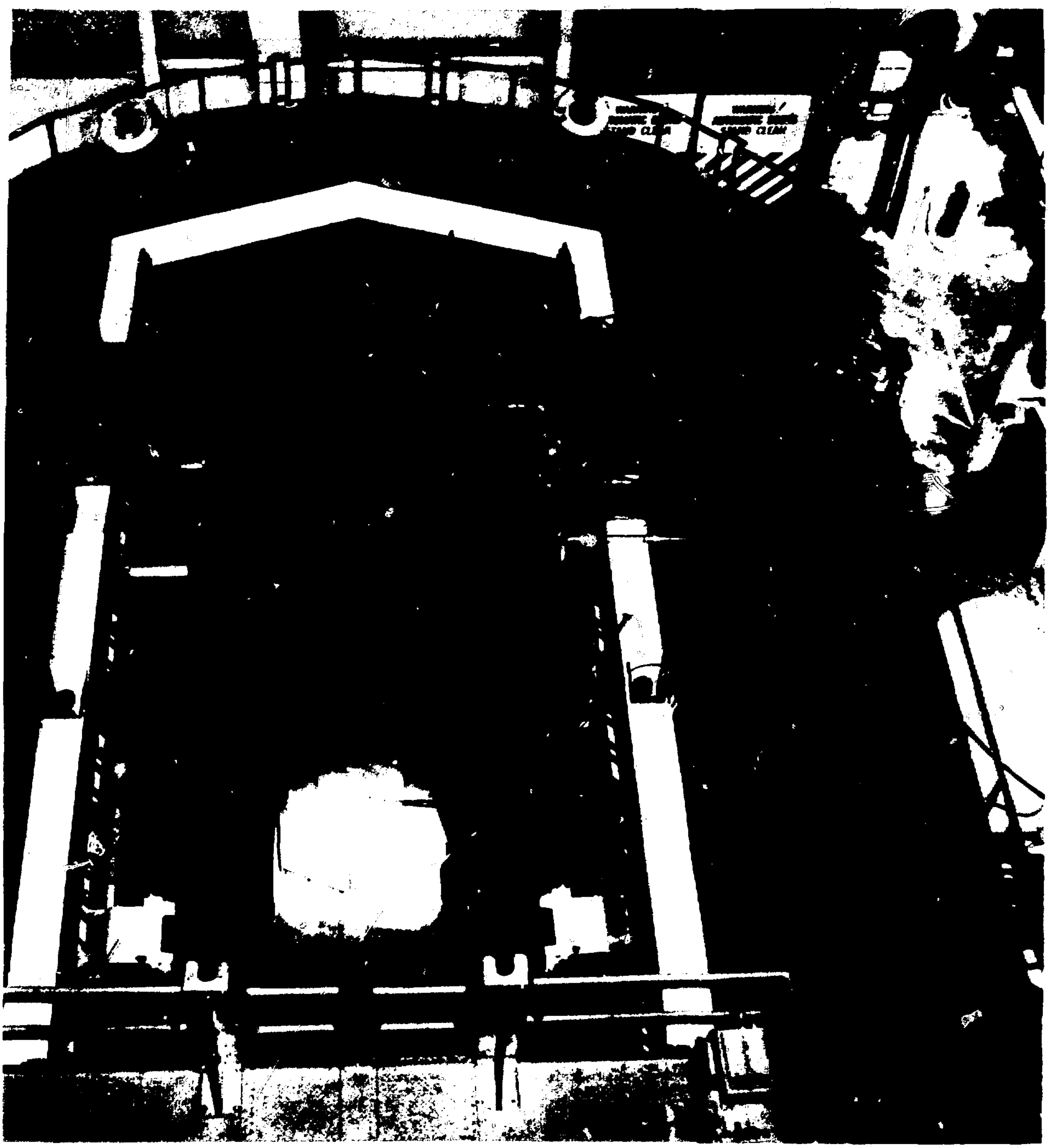
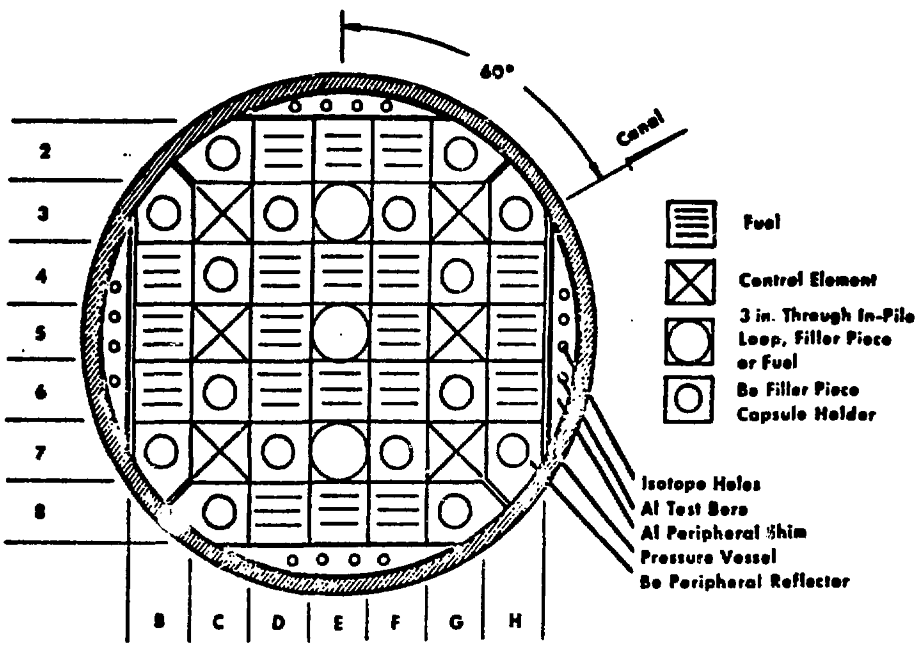
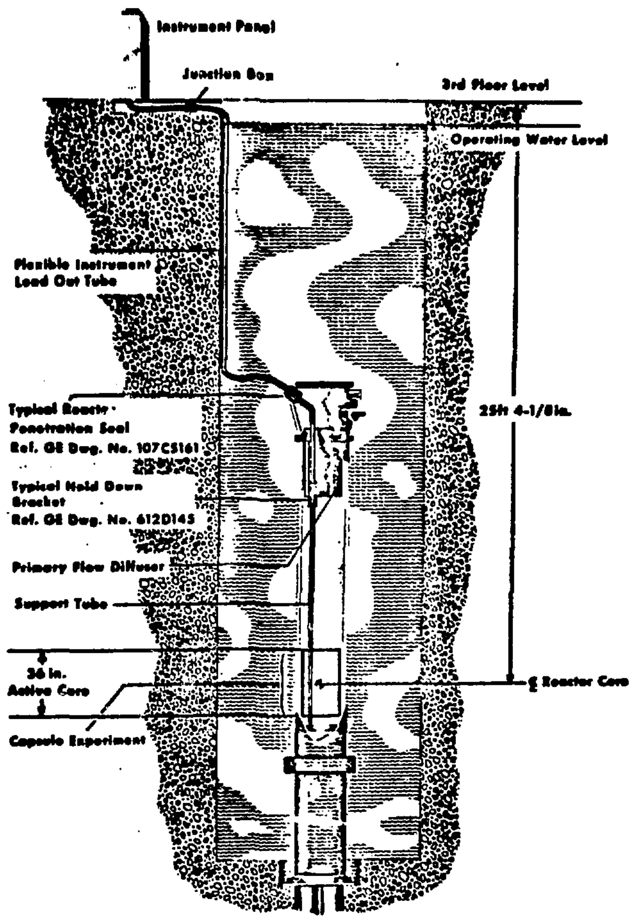


(4) Oak Ridge Research Reactor Pool, Courtesy of Oak Ridge National Laboratory.

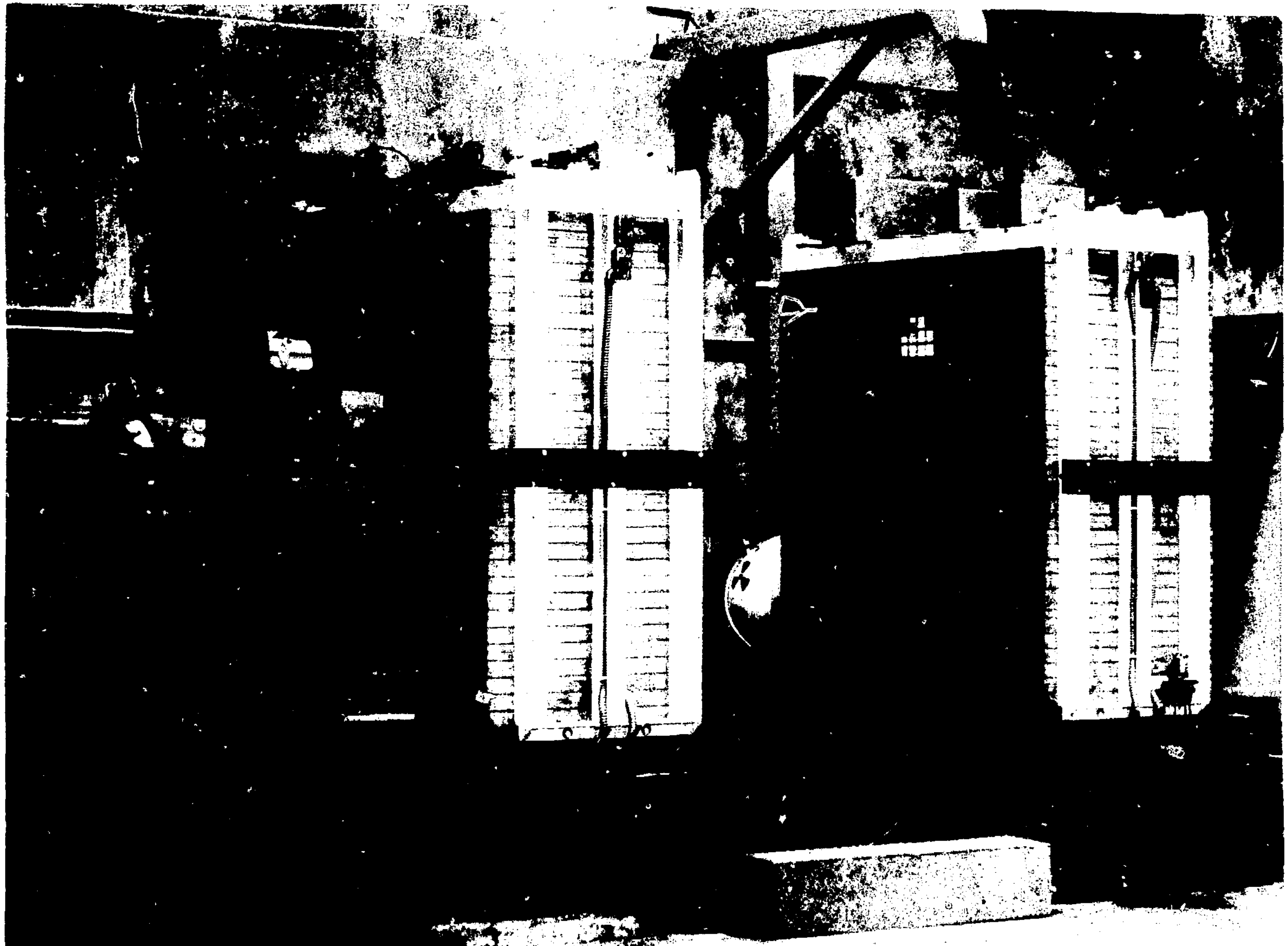
(5) CP-5 Research Reactor, Courtesy of Argonne National Laboratory.



(6) The GETR Core Matrix, Courtesy of the General Electric Company.



(7) Cutaway of the GETR with In-Core Test Assembly, Courtesy of the General Electric Company.



(8) ZPP-VI with Halves Separated, Courtesy of Argonne National Laboratory.

(9) Loading ZPPR, Courtesy of Argonne National Laboratory.

(10) Plutonium Fuel Fabrication Facility, Courtesy of Argonne National Laboratory.

(11) Remote Operated Hot Laboratory, Courtesy of Argonne National Laboratory.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #16: INSPECTION OF REACTOR AND SPENT FUEL STORAGE FACILITIES

SPEAKER: Bernardino Pontes

International Atomic Energy Agency
Vienna, Austria

Friday, May 30, 1980
2:00 p.m.

BIOGRAPHY

See Session 8b

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Session Objectives

SESSION #16: INSPECTION OF REACTOR AND SPENT FUEL STORAGE FACILITIES

Various aspects involved in the inspection of reactor and spent fuel storage facilities are discussed, including inventory verification, field measurements, sampling plans, verification of facility measurement systems, containment and surveillance, and IAEA inspection and verification. Techniques, methods, and instrumentation presently employed in national systems and in IAEA inspection and verification are described. The type of information that these inspections provide and how this information is used to establish and verify facility inventory and to detect and deter diversion are considered.

After the session, participants will be able to

1. Describe salient features of inspection of reactor and spent-fuel storage facilities.

2. Identify the various equipment, techniques, and methods used in this inspection.

3. Explain how the information obtained from the inspection is used to detect, deter, and discourage diversion.

INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

Topic 16: INSPECTION OF REACTOR AND SPENT FUEL STORAGE FACILITIES

L. Thorne
International Atomic Energy Agency

I. FEATURES RELATING TO SAFEGUARDS

Reactors and spent fuel storage areas possess features which it is often said make them the easiest of the major types of facility to safeguard. In the first place the material is in units in the form of rods or assemblies which, except in the case of a few research reactors, are not intended to be broken up. The problem of safeguarding these plants is then one of accounting for the presence and integrity of items, which is basically a much simpler task than that of accounting for material in bulk form such as in manufacturing or reprocessing plants. There is however a second feature to which attention is not so often drawn, which is that the quantity of material within the unit is not normally measured by the plant operator. Throughout the time the material is at the facility the quantities entered in the facility records are based on measurements made elsewhere or upon theoretical calculations of production and loss resulting from burn up of fuel.

From the operators viewpoint, the value of contained material within the assembly or rod is not something he would normally question. The fuel is manufactured to very tight limits with some of the strictest quality controls of any industry. Any defect in the fuel would show up in operation in the form of reduced performance with economic penalties. For an international safeguards monitoring system however reliance cannot be placed on such features, since a government wishing to divert material could well organize a systematic falsification through the manufacturing process and accept loss of performance in reactor output. Some form of fresh fuel verification is therefore essential for an international inspectorate.

Similarly, the reactor operator will have faith in his computer predictions of plutonium build up and uranium burn-up since his operating experience will readily identify any deficiencies in the computer codes. The fueling cycle is calculated and operated to fine limits with strong economic rewards and penalties for increased or decreased fuel lifetime or total heat output. A visiting inspector does not have this depth of information readily available to him and so requires reassurance on points which to an operator may seem self-evident.

To summarize the points being made here: in the bulk handling plants, material is in a form that is in principle easily diverted in small amounts. The operator however makes direct material measurements and these can be monitored by an external inspection system. In the reactor, material is in large contained items. No direct measurements of material are made however so an inspectorate must either devise NDA techniques for confirmation of quantities and/or institute containment and surveillance systems to maintain knowledge of item location.

II. DETECTION TARGETS

Before moving on to consider inspection procedures it is important to consider the objectives of an inspection system in some detail. Broadly speaking the objective of inspection is to "detect, deter and discourage diversion". An inspector however must have these objectives more precisely formulated. Other lectures will have mentioned IAEA criteria for what is regarded as a significant quantity of material in various forms, and will also have introduced the concept of detection time. In the case of power reactors using low enriched or natural uranium fuel it will be recalled that a significant quantity is regarded as 75 Kg of contained U235 or 8 Kg of Pu, with a detection time of 1-3 months for plutonium in irradiated fuel and one year for fresh uranium fuel. Because of the unit nature of the material in reactors, this is interpreted for light water reactors as a detection target of the absence of one or more spent fuel assemblies within two to three months, or the absence of one or more fresh fuel assemblies within one year.

III. DIVERSION POSSIBILITIES

Having considered the targets for detection we must now turn to the possibilities for diversion before forming our strategy. For convenience these are summarized on the following table. This also shows the methods by which the concealment of the diversion may be attempted. The third column shows the safeguards measures usually adopted to counter the concealment methods.

IV. INSPECTION PROCEDURES

In negotiating the details of the safeguards agreement, the Agency aims for a minimum of six inspections per year at LWRs, equivalent to 10-15 man-days a year. Note that this is a minimum figure to cover a straightforward case where containment and surveillance methods are fully used. The table just discussed has summarized some of the strategies to counter diversion, but now it is important to consider more fully the sequence of actions and the logic behind them.

The first activity during a routine inspection is the examination of the accounting records. This is done to ensure that adequate records are in fact being kept and to establish a book-figure for the material on site. This book figure is the operators statement of what he accepts responsibility for. This is the figure against which all plant records, shipping documents, and reports to the Agency will be checked. The checks of these documents will be for arithmetical correctness and internal and mutual consistency. As in conventional financial accounting, the thesis on which the approach is based is that while one or several documents may be falsified, the probability of successfully falsifying all documents is small and diminishes as the number of documents increases.

Table I. Summary of Diversion Possibilities for Reactor and Spent Fuel Storage Facilities

Diversion Possibilities	Concealment Methods	Safeguards Measures
Removal of fuel elements from the fresh fuel store	Substitution with dummies	Application of seals NDA measurements
Removal of fuel elements from the core	Substitution with dummies	Seals Optical surveillance
Irradiation of undeclared fuel elements in the core	Undeclared shutdowns	Seals Optical surveillance
Removal of fuel elements from the spent fuel pond	Substitution with dummies	Optical surveillance NDA measurements
Removal of fuel elements from consignment when or after they leave the facility	Substitution with dummies in consignment. Understating of number of elements shipped and substitution with dummies in the spent fuel pond	Sealing of shipping container before shipment and verification of content at recipient facility, if possible

As well as accounting records, operating records will be examined. The aim is to confirm that records of core changes and fuel movements in the accounting records are confirmed by records of the reactor state. Again the approach is that whereas a strip chart recorder of neutron flux in itself is only small confirmation of operating condition, several charts of various related parameters such as steam flow, reactor pressure, etc. are useful in establishing internal consistency.

Having completed an examination of records, the next step is to verify material. This activity starts at the fresh fuel store with a count of the number of assemblies in storage and an examination of serial numbers to identify the assemblies against shipping documents and plant records. In some cases seals may have been applied at the manufacturing plant after verifying the quantity of material present. Cameras may also have been in use to confirm that no movement of fuel has taken place in or out of the store. In cases where such measures cannot be applied, nondestructive measurements (NDA) may have to be taken. In the simplest case these may be by means of a simple "go no-go" type instrument such as a hand held gamma spectrometer preset to have an energy window at the U235 gamma energy peak.

Verification of the fuel in the core can of course only be done at refuelling periods when the reactor vessel is open. Practical considerations limit the verification to item counting and identification by underwater TV. Seals on the missile shield and surveillance cameras confirm that at other times the vessel head is not removed and so fuel movement cannot have taken place.

The strategically most important location in the reactor plant is the spent fuel storage pond. At this point plutonium-containing fuel accumulates for six months to a year. (With the present uncertainty over reprocessing the storage times are of course now being prolonged indefinately). Surveillance cameras play the most important role in safeguarding the area since the prime aim is to ensure that no undeclared shipments take place.

Agency practice at present is to use twin-camera units to provide redundancy. The cameras are movie-type set to give single shots according to signals from a random timer. The interval between shots is chosen to be less than the interval considered credible for any removal of a shipping flask. With present equipment this means that the maximum interval between visits to service the units is two to three months, which fits in conveniently with the chosen detection time in the Agency safeguards criteria. As an alternative to optical film cameras, TV systems are sometimes employed. These have the advantages of high sensitivity, ability to operate in almost total darkness, and very long intervals between service with a greater amount of information stored. The disadvantage is added complexity and cost.

At times the need may arise to carry out NDA measurements of the fuel in the spent fuel storage area. Such occasions have arisen where the evidence of the surveillance equipment is ambiguous or some other unusual circumstance has taken place. Equipment has been developed and used for such measurements using multi-channel gamma-ray spectrometers with collimators installed in the fuel pond. The information from a scan period of say 1000 s per assembly is stored on tape cassettes and analysed later by computer at headquarters. Suitable analysis gives information on irradiation times and cooling times based upon the isotopic composition of the fuel as shown by the gamma-ray spectrometer.

The techniques described have been those appropriate to an LWR reactor since this is the one most common encountered in safeguards work. They are just as appropriate for other types such as CANDU and Magnox providing the nature of the fuel in such types is taken into account. The principal difference is that in place of a hundred or so identifiable assemblies, one is dealing with tens of thousands of fuel rods. Although each rod does have an identification number from the manufacturer, the large number of rods makes it quite impracticable to work with the identity number. Inspection techniques become more akin to those for bulk-handling facilities since indeed one is dealing with a bulk of small items. Instead of accounting for and measuring individual items, sample plans are used to establish (say) that with 95% confidence not more than a certain number of rods may be missing. The "certain number" corresponds to the amount of material chosen as the detection target.

IAEA safeguards have been designed to impose the minimum possible burden on the operator consistent with the requirement upon the State that material can be accounted for. On the national level, inspections have additional functions such as ensuring operator compliance with national legislation, ensuring physical measures against theft are adequate and have been effective, and that staffing is adequate with accounting personnel adequately trained. The two systems are complementary. Without the prerequisites of the national system, the guarantees for the international system would have no basis.

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INTERNATIONAL TRAINING COURSE ON NUCLEAR MATERIALS ACCOUNTABILITY FOR SAFEGUARDS PURPOSES

SESSION #17: PREWORKSHOP SESSION (AND REVIEW)

SPEAKER: Dr. James P. Shipley

Los Alamos Scientific Laboratory
Los Alamos, New Mexico USA

Friday, May 30, 1980
4:00 p.m.

BIOGRAPHY

Education: Ph.D., Electrical Engineering, 1973, University of New Mexico; M.S., Electrical Engineering, 1969, University of New Mexico; B.S., Electrical Engineering, 1966, University of New Mexico.

Present Position: Group leader of Safeguards Systems Group, Q-4, at Los Alamos Scientific Laboratory.

Past Positions: Joined LASL in 1966 in Electronics group. In 1973 became Alternate Group Leader of E-3 (Electronics Division) working on design of instrumentation and control systems with application to solar heating and cooling. Joined Safeguards program in 1976. Background in Electronics, Automatic Control Systems, Filtering Theory, and Applied Mathematics for Systems Analysis.

Other Information: Wrote Chapter 4, "Decision Analysis for Nuclear Safeguards," to the book, Nuclear Safeguards Analysis: Nondestructive and Analytical Chemical Techniques. Member: Institute of Electrical and Electronics Engineers, the American Association for the Advancement of Science, the Institute of Nuclear Materials Management, and Sigma Xi.

Session Objectives

SESSION #17: PREWORKSHOP SESSION (AND REVIEW)

The workshop on national accountability system design to be conducted during the last two days of the course (Sessions 31 and 32) will require participants to make extensive use of the concepts presented before that time. The purpose of this session is to indicate what will be expected of participants during the workshop. The session should thus provide additional motivation for mastery of the various safeguards concepts presented, and should also provide an opportunity for questions and discussions on those concepts that may pose special problems or may not have been fully understood.

SESSION 17: PREWORKSHOP SESSION ON NATIONAL ACCOUNTABILITY SYSTEMS

Safeguards Systems Group (Q-4)
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I. INTRODUCTION

The workshop on national accountability systems design to be conducted during the last two days of the course (Sessions 30 and 31) will require extensive use of the concepts presented before that time. The purpose of this session is to indicate what will be expected of participants during the workshop. The session should thus provide additional motivation for mastery of the various safeguards concepts presented, and will also provide an opportunity for questions and discussions on those concepts that may pose special problems or may not have been fully understood.

This session will outline a general framework within which the workshop activities can be pursued, ultimately aiming at designing a State's system of accounting and control for the reference facility. The major areas where safeguards technology, which is presented throughout the course, can be brought to bear are discussed in terms of overall systems development.

II. THE DESIGN SEQUENCE

In the workshop we will be concerned with a particular stage in a complete design process, namely conceptual design. Conceptual design means different things to different people, but the meanings differ primarily in the level of detail that each would include. Fundamentally, conceptual design is the design (or selection) of concepts useful for solution of the problem at hand, and the formation from these of a larger overall solution concept. Thus, the conceptual design should be given in terms of (1) the functions that it and its subsystems must perform, and (2) an estimate of how well each function can be performed. The level of detail should be sufficient to allow at least a preliminary quantitative evaluation of the concept and to permit effective direction of design.

Conceptual design comprises five major steps, which may be iterated as necessary: (1) synthesis, (2) analysis, (3) evaluation, (4) modification and/or iteration, and (5) summation. This is only one way among many of partitioning the design process, but it includes all the necessary functions.

The flow chart of Fig. 1 illustrates the sequence of conceptual design steps, which are described below. Each step logically builds on previous steps, and portions of the sequence can be repeated for design refinement or improved design characterization. Clearly, if suitable definitions of the steps are made, this sequential procedure can serve as well for any stage in the design cycle.

A. Synthesis

Synthesis consists of combining building blocks into an orderly structure that would appear to be capable of reaching the system goals. The phrase "would appear to be capable" is appropriate at this point, prior to the analysis and evaluation steps that would determine the system's capability.

Synthesis can be broken into five parts:

1. Definition of total system objectives, specifically the performance measures for the whole system;
2. Determination of the system's environment, i.e., the fixed constraints, including such things as scheduling requirements and necessary interactions with other systems;

CONCEPTUAL DESIGN STEPS

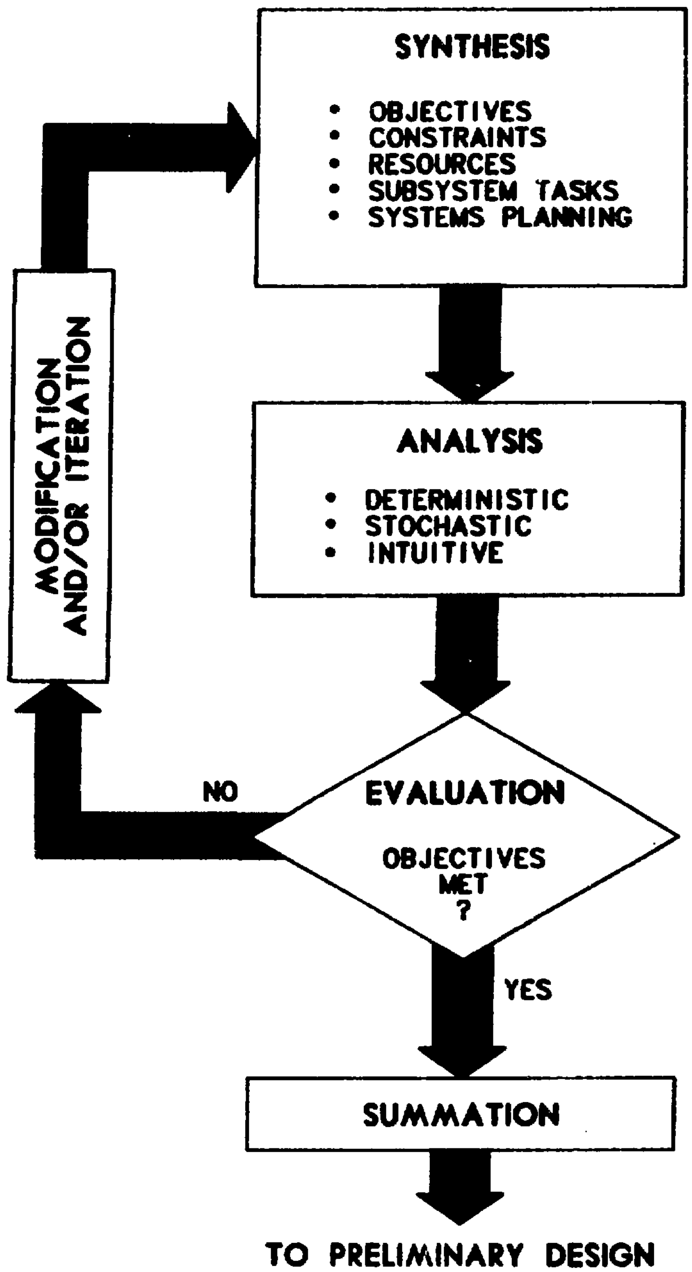

Fig. 1

3. Enumeration of the resources available to the system, for example, applicable technology, money, and human resources;
4. Definition of subsystem missions, that is, the functions the subsystems must fulfill to achieve the objectives of the system; and
5. Description of systems planning and operation, or how the subsystems fit together.

These five parts result in a system design that is ready for the next step, analysis. Notice that, in the early stages, the desired values of the system performance measures may not be known. Thus, one of the purposes of the conceptual design step is to ascertain those values of performance measures that seem attainable.

B. Analysis

Analysis quantifies the performance of the system obtained from the synthesis step. One of the primary tools of analysis is mathematical modeling and simulation based on either deterministic or stochastic formulations. Deterministic models are useful for characterizing systems that are well known and somewhat static, or for calculating nominal or average behaviors. Stochastic (or probabilistic) models attempt to account for uncertainties in the system, e.g., unmeasurable perturbations or measurement noises, by specifying properties of the uncertainties such as the density functions. The stochastic model is then run several times, each time with different sample functions from the uncertainty distributions, to give an idea of the system behavior on the average and its variation about the average. This is the so-called Monte Carlo technique.

Due to practical constraints (time, computer resource availability), analysis in the workshop will be limited to the deterministic approach.

C. Evaluation

In evaluation, the results of analysis are examined to determine whether the system meets the performance goals set in the synthesis step. If the goals have been specified as "best obtainable," then a comparison with previous results is necessary.

D. Modification and/or Iteration

Depending on the outcome of the evaluation, it may be desirable to return to the synthesis step and repeat the whole process with some system modifications.

E. Summation

After steps A-D have been iterated sufficiently to give a satisfactory system conceptual design, the results are compiled and summarized in the form of a point of departure for the next part of the design cycle. For the purposes of the workshop, the summation represents the final product, which will be discussed by the participants and lecturers.

III. SPECIFICS FOR THE WORKSHOP

During the course, material will be presented that will be useful in carrying out the design steps in the workshop. The following is intended as a guide to the types of information that will be needed. More detail will be given at the time of the workshop.

A. Synthesis

The systems goals are three-fold:

1. Effective materials accounting, as measured by sensitivity to diversion;
2. Minimum operational impact, as measured by time delays in processing caused by safeguards; and
3. Minimum cost, as measured by the incremental increase in cost, both capital and operating.

Several other goals could be listed, but close examination shows that they are all subgoals under one of these three.

The systems environment, or fixed constraints, includes:

1. The original facility design,
2. The operational procedures of the facility,
3. The limits of current technology,
4. The attitudes of the process operators toward safeguards, and
5. Regulations governing the facility.

Although 1. and 2. are listed as constraints, they are not hard constraints in that minor modifications to the facility design and its operational procedures can be negotiated. The degree of hardness is related to how late in the design cycle safeguards criteria have been incorporated. Any assumptions made during the workshop should be explicitly stated.

The system's resources are numerous:

1. Modern technology, such as NDA instrumentation, conventional chemical analysis, and computerized information processing;
2. Intimate knowledge of the process and its workings;
3. Past experience with safeguards systems;
4. Assistance from the physical protection system;
5. The good will of the process operators;
6. The weight of the regulatory authorities; and
7. Public opinion.

The subsystem missions for the materials accounting system comprise three parts:

1. Materials measurement: quantity and location,
2. Materials balance calculations, and
3. Data analysis for diversion detection.

Systems planning and operation involve the specification of such features as:

1. The definition of materials balance areas,
2. The frequency of drawing materials balances,
3. The decision structure for the safeguards system, and
4. The interface with international safeguards.

B. Analysis

The analysis should be made in terms of performance measures that relate to the system goals, that is, diversion sensitivity, operational impact, and cost. Sufficient detail will be given in the workshop to perform quantitative analyses. The methods for doing the analyses will be discussed during the course and made available for the workshop.

These items constitute the bulk of the information required for the workshop. The subsequent steps in the design sequence will build on this information and occupy most of the effort in the workshop. Lecturers will be available to consult on problems that may arise as the workshop proceeds.