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NONDESTRUCTIVE ASSAY TECHNOLOGY AND AUTOMATED "REAL-TIME" MATERIALS CONTROL*

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ABSTRACT

NONDESTRUCTIVE ASSAY TECHNOLOGY AND AUTOMATED "REAL-TIME" MATERIALS CONTROL

Significant advances in nondestructive assay techniques and instrumentation now enable rapid, accurate and direct in-plant measurement of nuclear material on a continuous or "real-time" basis as it progresses through a nuclear facility.

A variety of passive and active assay instruments are required for the broad range of materials measurement problems encountered by safeguards inspectors and facility operators in various types of nuclear plants. Representative NDA techniques and instruments will be presented and reviewed with special attention to their assay capabilities and areas of applicability in the nuclear fuel cycle.

An advanced system of materials control--called "DYMAC,"--for Dynamic Materials Control--is presently under development by the U.S. Energy Research and Development Administration; the DYMAC program integrates new nondestructive assay instrumentation and modern data-processing methods, with the overall objective of demonsrating a workable, cost-effective system of stringent safeguards and materials control in various generic types of facilities found in the nuclear fuel cycle. Throughout the program, emphasis will be placed on developing practical solutions to generic measurement problems so that

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resulting techniques and instrumentation will have widespread utility.

Projected levels of safeguards assurance, together with other vital--and cost-sensitive--plant operational factors such as process and quality control, criticality safety and waste management will be examined in an evaluation of the impact of future advanced materials control systems on overall plant operations, efficiency and productivity.

The task of implementing effective and stringent safeguards includes the transfer of new safeguards technology to the nuclear industry. Clearly the training of inspectors (both IAEA and national), plant people, etc., in the effective use of new NDA equipment is of paramount importance; thus in the United States, the Energy Research and Development Administration's (ERDA's) NDA training program, to be described, has proved a key factor in the effective transfer and implementation of NDA technology throughout the nuclear community.

1. INTRODUCTION

Non-proliferation of nuclear weapons is emerging as a dominant issue in American foreign policy and as well in U.S. domestic energy policy. [1] [2] The effective control of proliferation on a global scale will require an unprecedented multinational cooperative effort involving both nuclear supplier and recipient ("customer") nations. The implementation of an effective international or multinational safeguards regime must include a stringent, yet workable, materials control system incorporating proven safeguards technology and conforming to some minimum consensus standards (e.g. set by IAEA, by mutual agreement between supplier nations, etc) that establish required levels of performance and assurance against diversion.

The United States domestic safeguards strategy toward an integrated safeguards system (all of which could be applicable to the domestic safeguards systems of other nations and some of which could apply to the IAEA's system of international safeguards) is based on a defense-in-depth approach consisting of three basic subsystems: (1) physical protection, (2) material control and (3) materials measurement and accountability. [3] In simplest terms, physical protection focuses on people and ways of assuring that they act only within authorized bounds. Its primary function is to protect against an overt attack on nuclear installations or material in transit. This subsystem utilizes such measures as personnel identification, physical barriers, penetration alarms and protective response and recovery forces.

Material control focuses on the nuclear material itself and ways of assuring that it remains within authorized locations. Its primary function is to deter covert theft by trusted plant insiders, possibly in collusion with outside agents. This subsystem uses handling and processing procedures to limit access to SNM (special nuclear material) and to provide a high degree of surveillance and containment.

The measurement/accountability subsystem involves keeping detailed records ("book inventory") on the location and quantity of nuclear materials, and performing the appropriate measurements needed to verify the book inventory on a timely basis. The measurement/accountability subsystem provides final overall confirmation that the other two subsystems have indeed achieved their purpose. Moreover, in the event of failure of either the physical protection or material control subsystems, the measurement/accountability subsystem provides evidence that material has or has not been diverted and further provides detailed data needed to isolate the location and mode of subsystem failure. In the assessment of a nuclear blackmail threat, for example, it is essential that the materials measurement/accountability subsystem provide an accurate material balance on a continuous or "near real-time" basis. Thus, an effective measurement/accountability subsystem must (1) update the material inventory by frequent, rapid and accurate measurements and (2) record results of measurements and associated uncertainties in an organized, retrievable fashion.

The traditional methods of SNM accountability--weighing, assignment of concentration "factors" based on plant experience, off-site analysis of attribute samples, etc., generally fail to meet the key requirements of assay accuracy and timeliness. Moreover, increasingly stringent safeguards requirements have placed severe and growing demands on SNM measurement capabilities. To meet these unprecedented requirements, it has been essential to develop a new measurement technology--now commonly referred to as nondestructive assay (NDA). The new NDA techniques not only complement, but in several cases supplant, the traditional destructive assay methods of analytical chemistry.

The need for intensive development of new NDA instrumentation for future implementation of safeguards was recognized by the Atomic Energy Commission in 1966, and appropriate R&D programs were then undertaken to provide the necessary NDA technology base on a time scale consistent with the projected growth of the U.S. nuclear industry. Today ERDA's R&D programs on Safeguards technology [4] include development and application of NDA methods to all aspects of inspection, assay and accountability of fissionable material found in the nuclear fuel cycle, including feed and product as well as the wide variety of spent fuel, residues and wastes generated by the nuclear industry. New NDA techniques already perfected, under active development or presently in the conceptual stage, promise extensive application not only to safeguards inspection and surveillance, but also to more effective materials management, criticality safety, quality and process control and waste management.

The results of ERDA's R&D program in safeguards technology and the efforts of commercial instrumentation manufacturers have led to a variety of instruments for quantitative analysis of nuclear materials, for surveillance, and for personnel and vehicle monitoring. These instruments have been successfully evaluated and installed at facilities such as Hanford Engineering Development Laboratory, Goodyear

Atomic Corporation, Westinghouse-Cheswick, Babcock & Wilcox-NUMEC, General Electric, and Rocky Flats, as well as existing facilities at LASL and other ERDA sites. Some representative instruments and the assay applications for which they have been developed are summarized in Table I.

Based on analyses of in-plant instrumentation requirements, extensive interactions with plant operating personnel and long field experience with NDA measurement systems, certain basic "truths" have emerged as fundamental to the successful transfer of safeguards technology from the R&D laboratory into an operating plant. The development of workable, cost-effective safeguards systems requires close technical interaction with, and continuing cooperation from, plant personnel in an operating plant environment. To gain genuine and widespread usage (not just token acceptance) by plant personnel, safeguards instrumentation and techniques must solve real measurement problems in operating fuel cycle facilities, e.g., even the difficult-to-measure solid scrap and waste materials must be quantitively determined in order to close material balances. Thus, practical experience has shown that a "building block" approach to solving individual measurement problems as they arise in plant operation has proved to be the most effective method of achieving the desired end-product of an overall in-plant SNM measurement and control system.

To maximize cost-effectiveness and in-plant acceptability, safeguards systems should be integrated with plant process control, quality control and criticality control systems. Although the cost of a separate safeguards measurement and control system might of itself be an affordable burden, if the system interrupts or otherwise adversely affects plant output, the cost of reduced production would be directly charged to safeguards and the system would be summarily rejected by plant operators and managers alike.

Today's trend toward tighter regulation and increasingly stringent safeguards essentially dictates that safeguards criteria be fully incorporated at an early stage in the design of future nuclear facilities. Thus safeguards systems have evolved from the traditional role of an overlay or "retrofit" on existing processes and plants to become an indispensable component of future integrated facilities. In effect, then, safeguards considerations seem destined to become a major factor in the selection of process and construction alternatives in the nuclear facilities of the future.

2. NONDESTRUCTIVE ASSAY INSTRUMENTATION: APPLICATIONS AND AVAILABILITY

The widespread adoption of NDA instrumentation by industry is clearly dependent on the availability of such instrumentation on the commercial market. This in turn requires close liaison between the developers of safeguards instrumentation and qualified nuclear instrument manufacturers. In addition, there must be a strong economic incentive for manufacturers to provide a reliable and rugged product. NDA instrumentation R&D, and associated technology transfer, has thus far resulted in a number of commercial NDA instruments; [5] further progress in this area is needed, and a number of efforts in this direction are underway. [6] Some representative commercial instruments, their applications and approximate costs are described below.

Figure 1 shows a commercially available Segmented Gamma Scanner (SGS). The unit shown in the Figure was designed to assay low density ^{235}U or ^{239}Pu waste products in 55 gallon drums, although smaller containers can also be measured. The SGS employs the "passive assay" technique (i.e., naturally occurring gamma radiation is used as a direct "signature" of the fissile material). The signature gamma rays are observed using a high-resolution Ge(Li) detector and the data are corrected for sample attenuation by use of a separate transmission source. The sample is rotated and scanned vertically in 7.5 cm segments to reduce effects of sample inhomogeneity. A minicomputer (shown at left) controls the scanning and data acquisition, and performs real-time data analysis. The manufacturer reports that the SGS system will measure 5 or more grams of ^{235}U or ^{239}Pu to an accuracy better than ±20% in about 15 minutes. Segmented Gamma Scanner systems are available from Canberra Industries Inc. and Eberline Instrument Corp. (list price ∿ $60,000).

Two versions of commercial Reactor Fuel Rod Scanners are shown in Figure 2a and 2b. Fuel rod scanners measure both total fissile content (^{235}U and ^{239}Pu) and the pellet-to-pellet fissile-loading uniformity in PWR, BWR, and Pu recycle fuel rods. The scanner utilizes the "active assay" technique, i.e., an isotopic neutron source is used to induce fissions in the sample and delayed gamma ray detectors or neutron coincident counters are then used to detect the number of induced fissions and thereby determine fissile content. The output signal may be processed with a minicomputer or displayed on a chart recorder and used to automatically reject "out-of-spec" rods. Simultaneously, total counts may be integrated as the rod passes through the detector to determine total fissile content in the rod. Scanners can detect pellet-to-pellet differences between 5% and 15% and total fissile content from ±.5% to ±1% at a throughput of 1 to 4 rods per minute. Fuel rod scanners are available from National Nuclear Corporation and Intelcom Rad. Tech.* at prices ranging from $60,000 to $250,000 depending on the number of instrumented fuel channels and the degree of automation desired.

A commercial Neutron Well Coincidence Counter is shown in Figure 3. The well counter is a passive system used to assay Pu bulk fuel and scrap by measuring spontaneous fissions in ^{240}Pu. Neutron coincidence counting is used to discriminate between neutrons produced by spontaneous fissions and those produced by (α,η) reactions on light nuclei. Sample sizes up to 0.2m in diameter and 0.28m high can be accommodated in the central well. The sample is surrounded by a ring of high-density polyethylene containing 24 BF_3 thermal neutron detectors.

* Presently IRT Corporation

Masses of 1 gm to over 1 kg can be measured in counting times ranging from 30 seconds to 1000 seconds depending on sample size and assay precision desired. Typical performance is a 2% uncertainty in a ten minute count for a well-characterized sample containing 1 gm of ^{240}Pu. The instrument is available from National Nuclear Corp. at a cost between $30,000 and $40,000.

Other commercially available NDA instruments include "random driver" units used to measure high density bulk fuel and scrap ($30,000 to $60,000), ^{235}U portable enrichment monitors ($3,000 to $5,000), the "elephant gun" used to measure waste generated in LWR fuel fabrication facilities ($8,000 to $10,000) and the portable shielded neutron assay probes ("SNAP") used to measure ^{240}Pu in plutonium oxide and metal configurations ($3,000 to $5,000).

Some NDA techniques currently undergoing development, which will hopefully reach the commercial market relatively soon, include plutonium solution assay systems, absorption-edge gamma-ray densitometry techniques, specialized thermal neutron coincidence counters and a "^{252}Cf shuffler" for assay of irradiated fuel and "hot" scrap and waste materials.

3. NONDESTRUCTIVE ASSAY INSTRUMENTATION: PERFORMANCE CHARACTERISTICS AND RELIABILITY

A comprehensive study has recently been completed that reviews and assesses the performance characteristics and measurement reliability of nuclear material assay using analytical chemistry, calorimetry and NDA techniques. [7] The materials measured are generically grouped into feed, product, scrap and waste categories. The reliability comparisons are based on many hundreds of assay measurements which have been compiled and presented in reference 7. Since reliability can range from the excellent results that can be achieved under optimum conditions to fair or even poor results, e.g. stemming from poorly-defined or poorly-executed procedures or from inadequate control, the study gives ranges of precision and accuracy values in order to provide guidance in assessing overall measurement reliability.

Some salient features of this study are summarized in Table II. The terms precision and bias are used to describe the reproducibility and systematic error, respectively, of measurements by a given method in each specified material category. Measurement bias is generally caused by errors in calibration, nonrepresentative standards or improper measurement procedures. The precision and bias values shown in Table II are typical of results obtained under operating plant conditions rather than the more favorable conditions that apply in the instrument development laboratory.

The "product and feed" category shown in summary Table II covers a wide variety of material types including liquids, powders, fuel pellets, rods, etc. Therefore, the uncertainties shown cover a broad range, and reference 7 should be consulted for specific subcategories. Typical chemical analyses should yield precisions of ∿ 0.3% and biases less than 0.2%; in general NDA measurements do not provide the level of precision and accuracy attainable with chemistry. However, NDA techniques enable direct and rapid measurement of an entire product inventory and hence do not suffer from the familiar problems of representative sampling and relatively long time delays associated with chemical measurements.

So-called "scrap" materials are defined as process residues that contain an economically recoverable amount of nuclear material. Scrap composition ranges from reject-product and feed-material to "dirty" residues containing less than 10 w/o nuclear material. Reject product and feed, the most common form of scrap, may be assayed by the same methods as product materials with similar reliability. Lower SNM-content residues and "dirty" scrap are generally less well characterized and exhibit correspondingly larger uncertainties as shown in Table II. Because representative samples of dirty scrap are usually difficult to obtain, the overall accuracy of NDA measurements is often as good as, or better than, analytical chemistry results.

"Waste" materials are residues that do not contain economically recoverable amounts of nuclear material. They are usually less dense, more heterogeneous and are stored in larger containers than scrap. In general, waste constitutes less than 2% of plant throughput, so a relatively large error on the measurement of waste can be tolerated with minimal impact on the overall material balance. Because of the sampling problem, waste is usually not amenable to chemical analysis (except for low level solutions) so assays are generally limited to NDA techniques. Reliable waste measurements require use of proper standards and separate transmission measurements (in the case of gamma ray techniques) to correct for sample self absorption. Waste measurements have frequently been performed without proper precaution in these areas, resulting in the relatively large biases shown in Table II.

4. IN-PLANT DYNAMIC MATERIALS CONTROL: THE DYMAC PROGRAM

Extrapolation of current NDA technology to an entire nuclear plant leads logically to a plant-wide network of on-line NDA measurement and verification instruments interfaced to a computerized materials accountability and control system. Such a "model" nuclear materials control system, called DYMAC (for Dynamic Materials Control), is currently under development by ERDA at the Plutonium Process Facility of the Los Alamos Scientific Laboratory. [8] [9] Coupled with a plant-wide surveillance system, DYMAC incorporates the following key elements: (1) an in-line and at-line measurement system relying heavily on newly developed NDA instruments to provide "real-time" quantitative assay data at key measurement points, (2) direct automated transfer of data from the plant floor into a central computer via interactive display terminals at selected measurement stations, and (3) an automated accountability system to provide rapid status on material balances for much smaller segments of the plant than have been customarily considered heretofore.

Under DYMAC, material balances are drawn around each "unit process," which is defined on the basis of process logic, residence time of material in process, and/or accessibility for measurement. For example, a unit process could be a dissolver tank, a single ion-exchange column, or a storage area. All materials flowing into and out of a unit process, including residues and waste, are measured using nondestructive assay equipment or the most rapid chemical analysis methods available. Measurement data are used to file transactions of material flows, from one unit process to another, in a central SNM accounting computer.

The DYMAC system will be implemented at Los Alamos in three phases. In Phase I, which is already underway, the present Los Alamos plutonium facility (DP-Site) is being used as a test bed for instrument development, interactive computer accountability and operator training. During Phase II the newly-developed technology, equipment and experience will be integrated into the new Plutonium Facility (TA-55) presently under construction at Los Alamos. Completion of the second phase is scheduled for June, 1978. Phase III is a program to demonstrate and evaluate system performance at the new plutonium facility. Throughout the DYMAC program, emphasis will be placed on developing practical solutions to generic problems of SNM measurement and control so that resulting safeguard techniques and instrumentation will be highly transferable and will have immediate widespread applicability.

In preparation for installing DYMAC at the new plutonium facility, three areas of activity are being pursued at DP-Site: evaluation of in-line NDA instrument performance; upgrading of the existing out-of-line instrumentation; and operation and in-plant evaluation of a prototype four-terminal accountability system.

In addition to digital-balance weight measuring equipment, there are currently two NDA measurement systems incorporated within operational gloveboxes at DP-Site: a neutron coincidence counter to assay pure oxide, waste and residues and a solution assay system to measure plutonium concentrations ranging from .1 gm/ℓ filtrate solutions to ∿ 200 gm/ℓ nitrate solutions. The high resolution gamma solution assay system can be readily modified to measure plutonium isotopic compositions. The corrosive atmosphere and relative inaccessibility to the interior of operational plutonium gloveboxes pose special problems for continuously operating and highly-reliable NDA instrumentation. Therefore, the design philosophy has been to keep delicate instrument and electronic parts outside the glovebox whenever possible. This is illustrated in Figure 4, which shows the incorporation of an in-line neutron coincidence counter into a glovebox. The cylindrical extension above the glovebox is a contiguous counting chamber into which samples to be assayed are raised by a pneumatic piston. The detectors and electronic components are all located outside the glovebox for protection and maintenance accessibility. Similar precautions have been taken for the in-line glovebox solution assay system. Close cooperation between NDA instrument developers and process-line operators is clearly required in the successful design of NDA instruments for operation in the highly-restrictive glovebox environment.

NDA instrumentation has been used routinely by process personnel at DP-Site for several years. Present out-of-line instrumentation includes two segmented gamma scan units to measure low-density scrap and waste, two thermal neutron coincidence systems to measure high-density residues, and a low-level waste assay device ("MEGAS") to sort waste containers according to the 10-nCi/g fiducial for segregating waste into retrievable or non-retrievable storage. Ongoing standards and measurement control programs are in progress for each of these NDA instruments.

Four remote terminals have been installed at appropriate locations in the DP-Site facility to collect data from each of these NDA instruments in order to close the material balance around a representative Pu nitrate-to-oxide conversion process. This prototype automated SNM measurement system at DP-Site is now fully operational and is being used to test the major functions that will be incorporated into the new plutonium facility at TA-55.

The full DYMAC system at TA-55 is expected to consist of some 15 "unit process" accounting areas, with ∿ 30 terminal locations, some 34 electronic-balance weighing devices and ∿ 30 NDA instruments of various types. The effectiveness of the DYMAC/TA-55 planned system will be evaluated using computer simulation studies which will provide limit-of-error calculations for each unit process.

Although the full-scale DYMAC concept must be thoroughly evaluated and demonstrated in actual operating nuclear facilities before its full potential and cost-effectiveness can be accurately gauged, it is already clear that DYMAC technology promises substantial economic benefits through timely measurement of in-plant holdup, improved process and quality control, operational safety, and waste management. Indeed a DYMAC-type in-plant materials control system may provide not only the most economic, but perhaps the only, feasible means of meeting increasingly stringent safeguards, security and safety regulations governing the operation of modern nuclear process facilities.

5. INTEGRATED SAFEGUARDS SYSTEMS DESIGN AND IMPLEMENTATION

Looking toward the future, in early 1976 ERDA initiated an Integrated Safeguards Design, Test and Evaluation program--a companion program to DYMAC--which will provide design requirements for cost-effective integrated safeguards systems with an optimum mix of physical security and in-plant materials control and accountability. [10] Program goals are to establish design and performance requirements for generic fuel processing facilities, and to assess the impact of these requirements on future plant design criteria. The functions of these generic facilities include uranium enrichment, spent fuel reprocessing, plutonium nitrate-to-oxide conversion, plutonium recycle fuel fabrication, and waste handling and disposal.

As part of this program a conceptual design of an integrated safeguards system for a commercial mixed oxide fuel fabrication facility has been completed. [11] [12] The baseline facility for the study was the projected Westinghouse Anderson Recycle Fuel Plant with an assumed annual throughput of 8000 kg Pu. The study assumed only minor extrapolations of existing fuel fabrication technology and state-of-the-art NDA technology. The safeguards system was designed to be highly automated, reliable and unobtrusive, interacting with process operations in a passive manner. Feasibility and effectiveness of the system was quantitatively assessed by applying diversion detection algorithms to results of computer simulated models of process operations and SNM measurements. Typical diversion-detection sensitivity levels in major plant process areas are: 100-200g Pu (about 2% of throughput) for a single theft; 200-400g Pu (about 0.2% of throughput) for cumulative multiple-small-thefts over any one-week period; and 400-800g Pu (about 0.1% of throughput) for cumulative multiple-small-thefts over any four-week period.

The capital cost of the DYMAC-type system is expected to be under 5% of total plant cost, and the safeguards staff (excluding guards) is projected at ∿ 8% of the total plant operating staff. Thus, this study indicates that current safeguards technology can provide a means for effectively safeguarding strategic quantities of SNM in a mixed oxide fuel fabrication facility at an acceptable cost and with minimal disruption or modification of production processes. The same methods and techniques successfully used in this mixed oxide facility design will be employed in the design of integrated safeguards systems for different types of generic and plant-specific facilities throughout the nuclear fuel cycle. In this connection it should be noted that the requirement for more and more stringent safeguard systems in future fuel cycle facilities has, of necessity, brought the nuclear facility designers and safeguards systems developers together in a mutual effort to incorporate stringent safeguards criteria at the very onset of new facility designs. Consequently safeguards considerations can be expected to influence significantly the selection and/or development of new processes and material flow paths in future facilities.

6. SAFEGUARDS TECHNOLOGY TRANSFER AND TRAINING

To implement the transfer of NDA technology to various types of plants and facilities in the nuclear fuel cycle, the U.S. Energy Research and Development Administration has established at Los Alamos the U.S. ERDA Nondestructive Assay Training Program [13] which is open to safeguards inspectors and qualified users (both domestic and international) of NDA equipment. Typical curricula (for one-week courses) are: (1) basic passive gamma and neutron assay, emphasizing the use of portable instrumentation, (2) an advanced course in high resolution gamma-ray assay, (3) an advanced course in active neutron assay, and (4) an advanced course in in-plant NDA instrumentation. These ERDA courses emphasize basic principles and practical skills through "hands on" experience with NDA instruments being adopted and used increasingly by safeguards inspectors as well as plant personnel.

The interests, viewpoints and SNM measurement problems of various organizations and agencies in the application of NDA technology are diverse. Thus the safeguards inspection and verification problems of the IAEA on the international level or those of NRC and ERDA in the U.S. national system can be quite different from the problems of production facilities, where the major concern is with plant output, product control, and simply complying with minimum safeguards regulations. Knowledge of, and sensitivity to, these many different problems and requirements is essential to responsive and productive research and development programs in ERDA laboratories. The ERDA NDA Training Program provides an excellent opportunity for such exchange of differing viewpoints and discussion of plant-specific problems.

The effectiveness of the IAEA inspector at nuclear facilities is clearly emerging as a crucial factor in achieving credible and technically supportable assurance of non-proliferation in the world community. An active inspection program must employ NDA techniques to verify inventories of SNM at nuclear facilities. The development of NDA instrumentation to enable the IAEA inspector to cope with a wide variety of generalized and specific measurement situations is being vigorously pursued as part of the program for expanded U.S. assistance to the IAEA. The goal of this development program is to provide the IAEA safeguards inspector with the technical capability for drawing reliable, timely, in-the-field conclusions re the current status of SNM inventories at facilities undergoing IAEA inspection and verification.

Though admittedly only part of the overall solution to effective international control of nuclear weapons proliferation, modern safeguards technology is clearly destined to play a key role in achieving stringent and effective safeguards in all major types of facilities throughout the nuclear fuel cycle.

REFERENCES

[1] Office of the White House Press Secretary, "Statement by the President on Nuclear Policy," October 28, 1976

[2] JIMMY CARTER, "Remarks on Nuclear Policy," San Diego, CA, September 25, 1976. Reprinted in Congressional Record, Vol. 122, No. 151 - Part IV; October 1, 1976

[3] "Master Plan," Division of Safeguards and Security, ERDA, H. E. LYON, Director, September 1976

[4] G. R. KEEPIN, "Safeguards Technology: Present Posture and Future Impact," First Pacific Basin Conference on Nuclear Power Development and the Fuel Cycle, Honolulu, Hawaii; American Nuclear Society, October 11 - 14, 1976

[5] DARRYL B. SMITH and IVAN WADDOUPS, "Safeguarding Nuclear Materials and Plants," Power Engineering, November 1976

[6] N. ALIKONIS, J. GRAY, J. POWERS, J. YOUNG, International Energy Associates Limited, "Review of ERDA DSS Program," Vol. I, October 1976; "Technology Transfer Handbook," Vol. II, January 1977

[7] T. D. REILLY and M. L. EVANS, "Measurement Reliability for Nuclear Material Assay," Los Alamos Scientific Laboratory, Report LA-6574 (to be published)

[8] G. R. KEEPIN and W. J. MARAMAN, "Nondestructive Assay Technology and In-Plant Dynamic Materials Control - 'DYMAC'," IAEA-SM 201/32, Proc. Inst. Symp. Safeguarding of Nuclear Materials, Vienna, (Oct. 1975)

[9] R. H. AUGUSTSON, "Development of In-Plant Real-Time Materials Control: THE DYMAC PROGRAM," Journal of the Institute of Nuclear Materials Management, Vol. V, No. III, Fall 1976

[10] L. M. BRENNER and S. C. T. MC DOWELL, "ERDA's Integrated Safeguards System Program," Journal of the Institute of Nuclear Materials Management, Vol. V, No. III, Fall 1976

[11] J. P. SHIPLEY, D. D. COBB, R. J. DIETZ, M. L. EVANS, E. P. SCHELONKA, D. B. SMITH, R. B. WALTON, "Coordinated Safeguards for Materials Management in a Mixed Oxide Fuel Facility," LA-6536, Los Alamos Scientific Laboratory (to be published)

[12] A. WINBLAD, Editor, "A Concept and Preliminary Definition of an Engineered Safeguards System for a Mixed Oxide Fuel Fabrication Facility," SAND 76-0528, Sandia Laboratories, September 1976

[13] R. H. AUGUSTSON, T. D. REILLY, and T. R. CANADA, "The LASL-U.S. ERDA NDA Training Program," Journal of the Institute of Nuclear Materials Management, Vol. V, No. I, Spring 1976

TABLE I

SELECTED NONDESTRUCTIVE ASSAY INSTRUMENTATION

Instrument	Principle of Measurement	SNM Measured	Field Use
In-Line Liquid UF_6 Enrichment Monitor	Passive gamma counting of 186-keV gamma ray from U-235; gross neutron activity from F(α,n)Na, alphas from U-234	% U-235 and U-234 in liquid UF_6	GAT gaseous diffusion plant (2 yrs.)
Portable U-235 Enrichment Monitor	The net count under the 186-keV gamma-ray peak is proportional to the U-235 enrichment in "thick" materials.	% U-235 in U, UO_2, UO_3, UF_6, UF_4, etc.	Oak Ridge, GAT, LASL GE, ERDA, NRC, IAEA
Segmented Gamma Scanner (SGS)	Passive gamma radiation is related to fissile content by correcting for attenuation with a separate transmission source.	U-235, Pu-238, & Pu-239 in waste and scrap	ARHCO, GAC, LASL
Thermal Neutron Coinc. Counter	Passive counting of coincidence neutrons from the spontaneous fission of Pu-240, Pu-238, Pu-242.	Eff. Pu-240 in Pu, PuO_2, $(U,Pu)O_2$	Richland (CSMO), Oak Ridge, LASL, IAEA
Random Driver Mod V	Material is irradiated with subthreshold neutrons from four AmLi sources, induced fissions are detected by neutron coincidence counting.	U-235, Pu-239, & eff. Pu-240 in metals, alloys, compounds	Savannah River, Oak Ridge, GAC, LASL
Reactor Fuel Rod Scanner	Thermal neutron interrogation with both prompt-neutron counting for total fissile and delayed gamma-ray counting for pellet-to-pellet assay.	U-235 and Pu-239 in PWR, BWR, Pu recycle fuel rods	Commercial versions at GE, Westinghouse, B&W
FFTF Fuel Rod Scanner	Passive gamma counting for pellet-to-pellet uniformity, neutron interrogation (Cf-252) with delayed gamma counting for Pu-fissile, neutron coincidence counting for Pu-nonfissile.	Fissile and non-fissile Pu content of FFTF fuel rods and pellets	HEDL (35,000 rods)
Photoneutron Assay System	Neutron interrogation (Sb-Be or Ra-Be) with prompt neutron counting via He-4 detectors	U-235, Pu-239 in irradiated fuel	NVOO (1.5 yrs.)
Cf-252 Assay System ("Shuffler")	Fast or thermal neutron interrogation with delayed neutron counting using He-3 detectors.	U-235, Pu-239 in bulk (solid or liquid)	LASL

TABLE II

NUCLEAR MATERIAL MEASUREMENT PERFORMANCE CHARACTERISTICS AND RELIABILITY

Material	Method	Precision[a] (RSD, %)	Bias (%)
PRODUCE AND FEED	Chemical assay	.1- .8	0 - .3
	Calorimetry	.3-1.0	0.1-0.2
	NDA	.3-2.0	.1-1.0
"DIRTY" SCRAP	Chemical assay	2	1-5
	Calorimetry	3	2
	Gamma (Transmission>0.1)	2	1-2
	Gamma (Transmission>.001)	2-10	2-5
	Neutron coincidence	3-10	1
	Active assay	8	.5-2.5
WASTE			
Large volume plutonium waste ($\geq 0.1M^3$)	Gamma	10-13	5
	Gamma (without transmission correction)	20	10-20
	Neutron coincidence	10	5
Small volume plutonium waste	Gamma	3	1-2
Large volume uranium waste	Gamma	10	5-10
Small volume uranium waste	Gamma	5	2

(a) RSD = relative standard deviation (1σ)

LIST OF FIGURE CAPTIONS

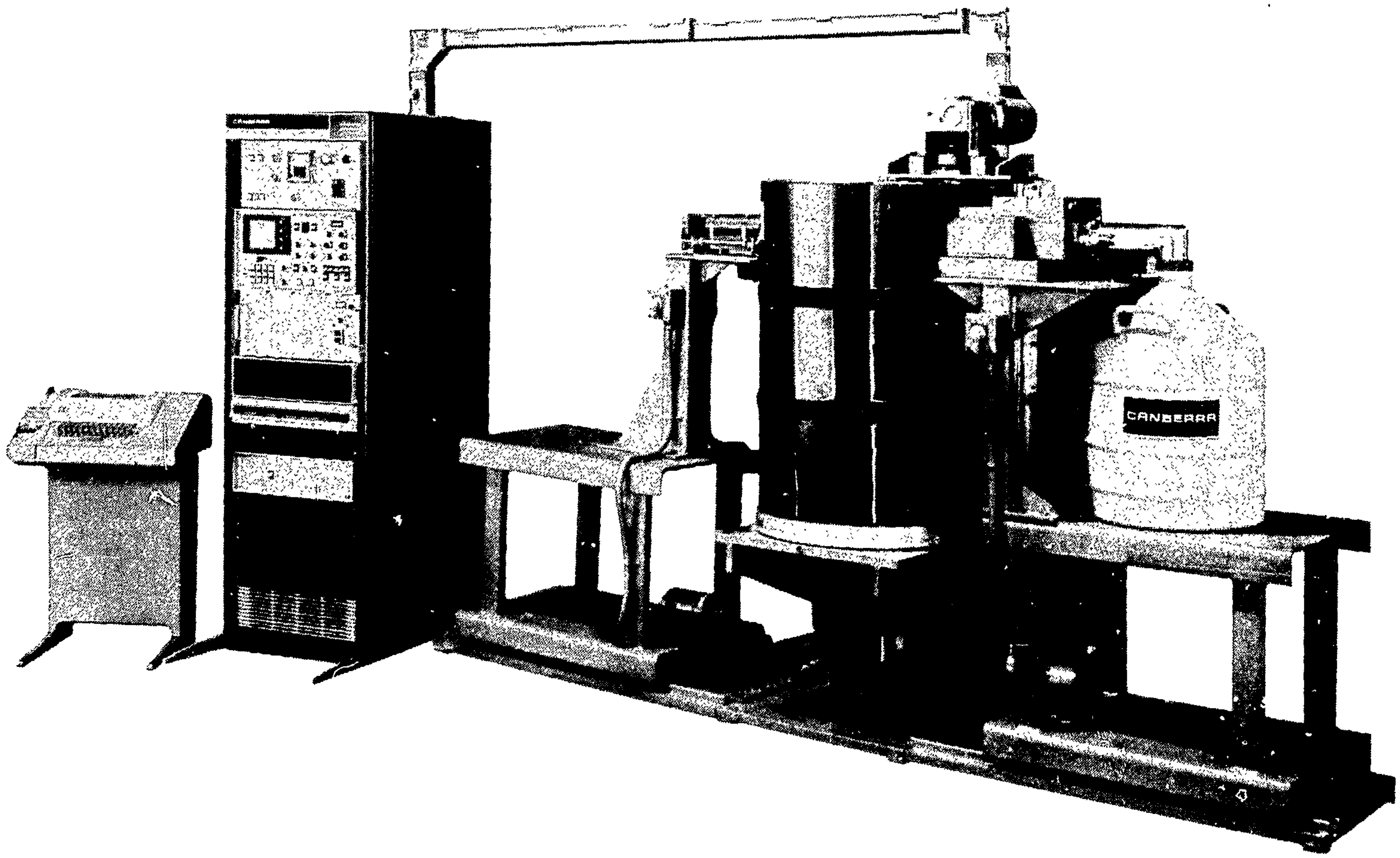
FIG. 1 Automated Segmented Gamma Scan System
Measures ^{235}U or ^{239}Pu content through detection of naturally-occurring gamma ray signatures using a high resolution Ge(Li) detector; system employs isotopic transmission source to correct for sample attenuation.

FIG. 2 Automated Fuel Rod Scanner Systems
a (upper photo) IRT system employing ^{252}Cf neutron source interrogation and measurement of delayed gammas.

b (lower photo) NNC system employing ^{252}Cf neutron source interrogation and measurement of coincident neutrons and gammas from fission events.

FIG. 3 Neutron Well Coincidence Counter
System measures plutonium content of $\leq 20\ell$ samples by coincidence counting of ^{240}Pu spontaneous fission neutrons.

FIG. 4 Glovebox incorporating contiguous counting chamber used for in-line nondestructive assay of plutonium via neutron coincidence counting of ^{240}Pu spontaneous fission neutrons.


CANBERRA