*Safeguards and Security Research and
Development Progress Report*

October 1993–September 1994

*Compiled by
Darryl B. Smith
Genara R. Jaramillo*

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Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

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SAFEGUARDS AND SECURITY RESEARCH AND DEVELOPMENT PROGRESS REPORT

October 1993 - September 1994

**Compiled by
Darryl B. Smith and Genara R. Jaramillo**

ABSTRACT

This report describes the activities carried out by the Los Alamos Safeguards and Security Research and Development (R&D) program from October 1993 through September 1994. The activities presented in the first part of the report were directed primarily to domestic US safeguards applications and were, for the most part, sponsored by the Department of Energy's Office of Safeguards and Security (DOE/OSS, NN-50). The activities described in Part 2, International Safeguards, were supported by the International Safeguards Division of the Office of Arms Control and Nonproliferation (DOE/OACN, NN-40). Part 3 describes several safeguards or safeguards-related activities that have other sponsors. The final part of the report lists titles and abstracts of Los Alamos safeguards R&D reports, technical journal articles, and conference papers that were published or presented in 1994.

Part 1 covers the three project phases—science and technology base, concept and demonstration, and full-scale development—that are part of the development of the technology essential to continuing improvements in the practice of safeguards and security. Examples include advanced portal monitor technology, digital image analysis for materials control, neutron multiplicity counting techniques, and development of a tomographic gamma-ray scanner. It treats activities aimed at developing methods for designing and evaluating safeguards systems, with special emphasis on the integration of several sub-systems into a real safeguards system. An example is the development of LANMAS, our Local Area Network Materials Accountability System.

Activities are described that are specifically directed to the transfer of safeguards technology, including direct assistance to the DOE and its contractors as well as consultation on materials control and accounting problems, development and demonstration of specialized techniques and instruments, and comprehensive participation in the design and demonstration of advanced safeguards systems. Although, in several cases, the implementation of advanced technology is described, the implementation parts of these projects were funded by DOE Program Offices, DOE Operations Offices, or by the facilities themselves, rather than the DOE/OSS; they are included in this report as the natural and necessary result of our R&D activities. Examples of technology transfer to industry also are described as is our extensive safeguards training program, which makes the technology more accessible to those who must apply it.

Although the technology described in Part 1 was funded primarily by DOE/OSS for application in DOE facilities, it also forms the fundamental technology base for applications in international safeguards and elsewhere.

Part 2 covers international safeguards activities, including technology developed for direct application in the international community, support to the International Atomic Energy Agency, and bilateral technical exchanges with many other States, such as France, Japan, Russia, Ukraine, and Kazakhstan. All of these efforts provide substantial returns on our investment in technology transfer, not only in raising the level of safeguards effectiveness throughout the world, but also in our benefiting from field experiences in operating environments.

Part 3 highlights a variety of projects, including several in computer security R&D, our direct support of the IAEA through the Program of Technical Assistance to IAEA Safeguards (POTAS), and safeguards projects funded by the US Department of State, the DOE's Office of Technology Development, the US Nuclear Regulatory Commission, and Japan. A few examples of these projects are our support for the holdup measurement campaign at Rocky Flats, nondestructive assay development for Warhead Dismantlement, and our activities in support of the Plutonium Disposition Project.

ACRONYMS

Argonne National Laboratory-West	ANL-W	Idaho National Engineering Laboratory	INEL
American National Standards Institute	ANSI	Integrated Holdup Measurement System	IHMS
Automated Retirement and Integrated Extraction System	ARIES	Institute of Nuclear Materials Management	INMM
ARGonne Unified Safeguards	ARGUS	inventory sample	INVS
acoustic resonance spectroscopy	ARS	International Standards Organization	ISO
American Society for Testing and Materials	ASTM	Independent Validation and Verification	IV&V
Advanced Thermal Reactor	ATR	Joint Photographic Experts Group	JPEG
Atomic Vapor Laser Isotope Separation	AVLIS	Japan Nuclear Fuels, Limited	JNFL
active well coincidence counter	AWCC	Los Alamos National Laboratory	LANL
bismuth germanate	BGO	Local Area Network Materials Accountability System	LANMAS
charge coupled device	CCD	Los Alamos Plutonium Facility	LAPF
Commissariat a l'Energie Atomique	CEA	low-enriched uranium	LEU
Continuous Neutron Monitor	CNM	light-water-reactor	LWR
containment and surveillance	C/S	multivariate adaptive regression with splines	MARS
Cooperative Research and Development Agreement	CRADA	Material Accountability and Safeguards System	MASS
containment/surveillance	C/S	Materials Accounting with Sequential Testing	MAWST
computerized tomography	CT	Miniature, Modular MultiChannel Analyzer	M ³ CA
Central Training Academy	CTA	multichannel analyzer-465	MCA-465
Combined Thermal/Epithermal Neutron	CTEN	materials control and accounting	MC&A
Decontamination and Decommissioning	D&D	Monte Carlo neutron and photon	MCNP
differential die-away techniques	DDTs	mixed oxide	MOX
Design Information Questionnaire	DIQ	material physical protection, control, and accounting	MPC&A
Department of Energy	DOE	material testing reactor	MTR
discrete wavelet transform	DWT	National Academy of Sciences	NAS
Experimental Inventory Verification System	EIVSystem	neutron coincidence counting	NCC
European Atomic Energy Community	EURATOM	nondestructive assay	NDA
Fuel Assembly Assay System	FAAS	nondestructive examination	NDE
facility simulation	FacSim	National Environmental Policy Act	NEPA
finite impulse response	FIR	Nuclear Emergency Search Team	NEST
Fissile Material Disposition Project	FMDP	Nuclear Regulatory Commission	NRC
Fuel Pin Assay System	FPAS	near-real-time accounting	NRTA
Fixed energy Response function	FRAM	National Security Agency	NSA
Analysis with Multiple efficiency	GBAS	Nuclear Fuel Cycle Safety Engineering Research Facility	NUCEF
Glove Box Assay System	FSU	Nuclear Materials Accounting System	NucMAS
Former Soviet Union	GG	Nuclear Materials Accounting System Limit of Error	NucMASloe
generalized-geometry	GGH	Office of Safeguards and Security	OSS
generalized-geometry holdup	GRAND	Office of Weapons Complex Reconfiguration	OWCR
gamma ray and neutron detector	GUI	Process Accounting Flow Diagrams	PAFDs
graphical user interface	HEU	personal computer	PC
highly enriched uranium	HP	PC-Dynamic Materials Accounting	PC-DYMAC
Hewlett Packard	HPGe	Programmatic Environmental Impact Statement	PEIS
high-purity germanium	HRGS	Plutonium Fuel Production Facility	PFPF
high-resolution gamma-ray spectroscopy	IAEA	Power Reactor & Nuclear Fuel Development Corporation	PNC
International Atomic Energy Agency	ICN		
Integrated Computing Network	ID		
intrinsic densitometry	IDGS		
isotopic dilution gamma-ray spectrometry	IDMS		
isotope dilution mass spectrometry	IEEE		
Institute of Electronics and Electrical Engineers	IINFO		
Inter-agency Information Network for NEST Field Operations			

portable multichannel analyzer	PMCA	specific memorandum of agreement	SMA
photomultiplier tube	PMT	Sandia National Laboratories-Albuquerque	SNLA
Program for Technical Assistance to IAEA safeguards	POTAS	special nuclear material	SNM
physical protection	PP	standard operating procedure	SOP
perfect-reconstruction, multi-rate filter bank	PR MFB	Shipper/Receiver Confirmatory System	S/RCS
research and development	R&D	Savannah River Site	SRS
Resource Allocation Optimization Program for Safeguards	RAOPS	States Systems of Accounting for and Control of Nuclear Material	SSAC
Record of Decision	ROD	Software Toolkit for Analysis Research test and evaluation	STAR
Region of Interest	ROI	Transmission-Corrected Gamma-Ray Nondestructive Assay	T&E
Rokkasho-Mura Reprocessing Plant	RRP	Tomographic Gamma-Ray Scanner	TCNDA
Real Time Radiography	RTR	tamper-indicating device	TGS
Safeguards and Security	S&S	Tokai Reprocessing Plant	TID
Space and Atmospheric Burst Reporting System	SABRS	transuranic	TRP
Synchronous Active Neutron Detection	SAND	Technical Working Group	TRU
Small Business Innovative Research Program	SBIR	Uranium Solidification Facility	TWG
Sintering Furnace Assay System	SFAS	Video Time Radiation Analysis Program	USF
segmented gamma ray	SGS	Westinghouse Hanford Corporation	VTRAP
Safeguards Information Management Systems	SIMS	Westinghouse Savannah River Company	WHC
		x-ray fluorescence	WSRC
			XRF

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Part 1. Domestic Safeguards Technology Development

PART 1. DOMESTIC SAFEGUARDS TECHNOLOGY DEVELOPMENT

I. SCIENCE AND TECHNOLOGY BASE DEVELOPMENT

A. Nuclear Materials Detection and Surveillance

The objective of the technology development task for nuclear materials detection and surveillance is to develop or improve materials control technology based on radiation detection used for detecting and confirming or verifying nuclear materials. The objective is also to provide information to assist the Department of Energy (DOE) and its contractors with the specification, evaluation, calibration, and proper use of the technology.

1. **Special Nuclear Material (SNM) Monitor Practice and Needs (P. E. Fehlau, NIS-6).** This year, we prepared a report¹ on our FY 1993 survey of individuals in the DOE complex who operate and maintain SNM monitors or who are contact persons for SNM monitor user needs. We found that the number of entry-control locations requiring SNM monitoring has been reduced through consolidation of SNM storage, some SNM monitoring equipment has been improved by upgrading or replacement with newer equipment, other improvements have been planned and are awaiting final review, and users generally are satisfied with the way we are meeting their needs. During our survey, we managed to satisfy a few emerging needs by suggesting commercially available SNM monitoring equipment, and we also received several requests that we should address to make commercial hand-held SNM monitors more rugged.

2. **Multichannel Analyzer-465 (MCA-465) Confirmation Instrument (P. E. Fehlau and D. A. Rutherford, NIS-6).** We evaluated the latest version of the MCA-465 instrument and found it to be very much improved. The remaining problems are very minor. The instrument should now be easily operable even by incidental users. In addition to the instrument, the operating and service manual is in good condition. We wrote and distributed an informal report on the final evaluation to interested potential users of the instrument. We completed a poster paper on our evaluation and presented it at the 1994 Annual Meeting of the Institute of Nuclear Materials Management (INMM) in July at Naples, Florida. The paper² will appear in the proceedings of the annual meeting. The MCA-465 instrument is now being used routinely at Rocky Flats.

3. **Integrated Neutron/Gamma-Ray Portal Monitor (P. E. Fehlau and D. A. Rutherford, NIS-6).**

Last year, we completed our integrated neutron-detection-based and gamma-ray portal monitor and evaluated a commercial prototype³ of it. This year, we presented a symposium paper on the integrated monitor that was also published in the *IEEE Transactions on Nuclear Science*.⁴ At present, the monitor is commercially available for applications that can benefit from the space and cost savings of having high-sensitivity neutron-detection-based and gamma-ray portal monitors located in a single footprint.

B. Materials Control Subsystems Definition and Development (C. A. Rodriguez and J. Brown, NIS-7)

The goal of this ongoing task is to provide the DOE complex with improved techniques for controlling and tracking materials that can be interfaced with materials accounting and physical protection subsystems. The task emphasizes definition and development of materials control components and subsystems for integration with other safeguards subsystems to provide defense-in-depth and to maximize total safeguards system effectiveness in upgraded or modernized facilities. Current emphasis is on the development of digital video technology for monitoring nuclear materials.

1. **Video Compression.** Data storage capability is of primary importance to the viability of digital surveillance systems developed for nuclear safeguards. To achieve the required compression ratios while maintaining minimal loss of quality in the reconstructed images, we determined that commercially available solutions like the International Standards Organization (ISO) "Joint Photographic Experts Group (JPEG)" image compression standard were not adequate. Instead, we adopted a wavelet transform compression algorithm based on predictive image coding strategies, currently being developed at Los Alamos.

Each frame is predicted from the previous frame, and the error residual (the difference between the actual and predicted frames) is coded for storage or transmission or both. The change detection algorithm plays an important role in the compression process in that it is used to adjust the quality level in the frame-difference coder based on the activity in the scene. By using relatively low-quality coding on frames with little activity, very large compression ratios can be realized.

a. **Discrete Wavelet Transform (DWT) Image Coding.** Compression of image frames is based on sub-band coding and adaptive uniform scalar quantization. The sub-band coder is a two-channel, perfect-reconstruction, multi-rate filter bank (PR MFB) with linear-phase finite

impulse response (FIR) filters corresponding to a family of regular, biorthogonal wavelets; this same PR MFB is used in the FBI's wavelet/scalar quantization standard for coding digital fingerprint images.^{5,6} The filters are applied to row and column vectors of an image using symmetric extrapolation at the image boundaries; this "symmetric wavelet transform" technique is described in Ref. 7. The resulting two-dimensional transform is then cascaded down five levels to produce the 16-band octave-scaled decomposition shown in Fig. 1. Note that this particular decomposition has fewer sub-band splittings than the decomposition employed in Ref. 5, which was tailored to preserve very fine details in fingerprint images at the expense of slightly increased ringing distortion near edges.

Once the DWT decomposition of an image has been formed, a bank of 16 uniform scalar quantizers is designed for quantizing the wavelet coefficients in the 16 sub-bands, based on the optimal bit-allocation problem: minimize the scalar quantization distortion model

$$D(\mathbf{r}) = \sum_{k=1}^{16} \frac{1}{m_k} \sigma_k^2 2^{-2r_k} ,$$

subject to the user-imposed constraint on the overall bit rate

$$\sum_{k=1}^{16} \frac{r_k}{m_k} = R .$$

Here, m_k is the down-sampling ratio for the k th sub-band; for example, the bands between $\frac{\pi}{2}$ and π in Fig. 1 have been down-sampled 2:1 in both the horizontal and vertical directions, so $m_k = 4$ for those bands. The other bands have down-sample factors that are higher powers of 4. The Lagrange multiplier solution to this bit allocation problem is

$$r_k = R + \frac{1}{2} \log_2 \left[\frac{\sigma_k^2}{\prod_j (\sigma_j^2)^{1/m_j}} \right] ,$$

which involves a "scaled" geometric mean of the sub-band variances. The derivation of this result is based on the assumption that

$$\sum_k \frac{1}{m_k} = 1 ,$$

a relation that holds for any critically sampled sub-band decomposition. An iterative procedure is used to eliminate sub-bands with negative "optimal" bit rates and ensure non-negativity of the r_k 's.

Fig. 1. Approximate frequency passbands for five-octave DWT decomposition.

The integer quantizer indices generated by the scalar quantizers are then compressed by zero-run-length and Huffman coding.⁸ Low bit-rates for the high-frequency sub-bands produce long runs of zeros in those portions of the sub-bands corresponding to smooth regions of the image; this is the principal source of additional lossless coding gain over and above the lossy gain produced by wavelet coefficient quantization. Note that this technique makes use of the good space/frequency localization properties of sub-band image coding with short FIR filters.

b. Predictive Coding of Image Sequences. Now consider coding a sequence or "run" $x_0, x_1, x_2, \dots, x_n$ of consecutive images taken by a still surveillance camera monitoring a scene of interest. The goal is to provide an uninterrupted record of surveillance images at very low storage costs during periods when the scene is inactive, yet obtain high-quality imagery during active periods. The initial frame rate is therefore assumed to be "low"; for example, one frame every few seconds. The initial frame in a run, x_0 , is compressed using nonpredictive coding. Because no motion is presumed to occur in the scene in the inactive state, we use a simple first-order predictor and code the difference frames for subsequent time-steps, $x_i - \hat{x}_i$, where $\hat{x}_{i-1}$ is the reconstructed, quantized approximation of x_{i-1} . The DWT is a linear transformation, so the transform d_i of the i th difference image can be computed by taking the difference of the DWT's, a_i and $\hat{a}_{i-1}$, of x_i and $\hat{x}_{i-1}$ as follows:

$$d_i = \text{DWT}(x_i - \hat{x}_{i-1}) = a_i - \hat{a}_{i-1} .$$

This eliminates the need to perform an inverse DWT inside the prediction feedback loop, improving on the predictive scheme described in Ref. 9. Note that a_i consists of 16 separate spatial frequency sub-bands, as shown in Fig. 1, so " d_i " denotes the difference signals for the 16 DWT sub-bands. The transformed difference d_i is quantized by the bank of uniform scalar quantizers described above and Huffman coded for transmission; the block diagrams for this predictive encoder/decoder system are shown in Figs. 2 and 3.

While the scene is inactive, the frame-to-frame differences are extremely small and can be coded at a very low bit rate with little perceptible distortion, allowing a continuous record to be archived at a low storage cost. Of course, as soon as an event occurs and the state becomes active, a much higher bit rate is needed to record the event accurately. A major advantage of adaptive scalar quantization is that the user-imposed overall bit rate R_i can be changed on the fly. In most image-sequence coding scenarios, it is very difficult to maintain constant perceptual image quality by automatically measuring scene content and adaptively modifying the quantizer bit rates. In the specialized remote surveillance scenario under consideration, however, image coding conditions divide naturally into active/inactive states, and there is a straightforward criterion for deciding when and by how much quantizer bit rates should be changed.

In Fig. 2, we have indicated how the transformed difference image, coupled with input from other sensors

(for example, motion or radiation sensors), can be fed to an event detector that automatically triggers a higher bit rate (and possibly an increased frame rate) in response to an event detection. Bit rates for the inactive state can be preset to minimize the amount of data required to verify that the scene remained unchanged when sensors detected no activity, and bit/frame rates for active states can be set high enough to provide necessary resolution for monitoring activities. This accomplishes our dual goals of providing uninterrupted coverage of the scene at very low storage cost during inactive states while still producing high-resolution coverage of active states.

2. Region of Interest (ROI). The Los Alamos Safeguards Systems Group has developed an image-based materials verification system that provides timely information about the state of nuclear materials in storage or in process. The Experimental Inventory Verification System (EIVSystem) is a prototype system that uses image processing and analysis technology to detect changes, or events, in the areas and materials being monitored. Detected events can be analyzed to determine their safeguards significance, retained for the historical record or ongoing analysis, and used to trigger alarms that bring the event to the immediate attention of operations or protection personnel.

Graded Protection. One drawback of simple video event detection is that it reacts equally to events in all parts

Fig. 2. Detector-activated predictive wavelet transform image coder.

Fig. 3. Predictive wavelet transform image decoder.

of the camera view; it does not distinguish between important and unimportant events. A simple motion alarm reacts to every change and movement, which is not always necessary. In any room, there are areas that require less security than others. Even high-security areas may include regions of low-security significance, like walkways and doorways; personnel movements there are normal and expected. Other parts of the room that contain sensitive objects must be watched more closely. The EIVSystem provides graded protection through ROI processing that allows the user to selectively protect regions within the field of surveillance.

Color Code and Levels of Security Region protection is provided in four color-coded security levels, allowing facilities to choose an event response appropriate to each region. The border color denotes the security level of the enclosed region: red for the tightest security, yellow for medium security, and green for the most casual security. Each color reacts differently to intrusion events:

- Red Starts the video recorder for the duration of the event. In the US, it sounds a loud alarm and calls security personnel.
- Yellow Snaps one picture, logs the intrusion. In the US, it quietly notifies security.

- Green Optionally records intrusion in log file for later audit; optionally records video. No alarms are sounded (authorized personnel movement is allowed.)

Un-colored (unenclosed) areas are not monitored.

Yellow zones are provided primarily as buffer zones between the highly responsive red zones and the mostly inert green zones, allowing personnel in green zones to work and walk near the protected red zones without the hazard of getting too close and setting off a full red alarm. Yellow zones may of course be used by themselves wherever a mildly alarmed area is desired (for example, in the upper right corner of Fig. 4).

Notice the drum in the red zone in Fig. 4; this drum has a loose paper tag that flutters when the vault's ventilation system is running. By enclosing this tag in a green region, we can prevent the tag from triggering motion alarms and still keep close watch on the rest of the drum. Shiny, reflective spots, which may pick up and mirror distant movements, can be handled similarly.

Using the EIVSystem ROI capability, safeguards personnel can now show the EIVSystem which objects in the room require protection and what level of alarm should be generated if the area is compromised. In effect, every

Fig. 4. The ROI Tool, showing top view of a storage vault. The user has divided the image into regions of interest (colored zones).

sensitive object in the room can be given its own separate alarm. This enhancement to the EIVSystem adds flexibility for users of the system and provides added protection against false alarms.

3. Multi-Media. We are developing several multi-media systems employing digital video image processing and analysis for application to the nuclear safeguards problem. Until recently, the use of video in domestic safeguards has been largely limited to live video displays located in central monitoring rooms. Typically these displays are in banks of nine or more monitors and are mainly used to view areas where other sensors have triggered an alarm. In international safeguards, still frames and video have been widely used for over ten years to record time lapse information about facility operations.

Early international still-frame systems simply recorded a still frame on film at predetermined intervals with the aid of an external, mechanical trigger. The film was periodically collected, developed, and reviewed by inspectors from the regulatory body. Current systems take advantage of personal computer (PC) and analog/digital tape technologies to drive the cameras and store the time-lapse imagery. Single images are collected by the computer system at programmed intervals, or when triggered by an external sensor, and recorded to tape that is then periodically (up to 3 months) collected and reviewed by the inspector.

We developed the Los Alamos EIVSystem to test the use of intelligent, automated surveillance in domestic safeguards. This system is installed at two DOE facilities and is currently undergoing final software modifications. It is scheduled to be fielded in late FY 1994. Another Los Alamos video system, the Video Time Radiation Analysis Program (VTRAP), is designed to be a next-generation video system for domestic safeguards.

a. The Experimental Inventory Verification System. The EIVSystem is a video-based surveillance application designed to help reduce the frequency of physical inventories in domestic nuclear materials vaults and long-term stores.¹⁰ This surveillance system is CPU-based and configured with one or more charge coupled device (CCD) cameras, a hard disk for data storage, and a tape archival system. The current implementation uses a Sun Microsystems SPARC architecture.

The EIVSystem is part of an overall defense-in-depth protection strategy that relies on multiple layers of security to provide complementary nuclear safeguards measures. This surveillance system is viewed as being effective against the "insider threat" because it does not depend on traditional monitoring devices that rely on receiving a positive signal to trigger an alarm. Such mechanisms, e.g., motion detectors, are perceived to be more vulnerable to insiders with a knowledge of the security apparatus. By contrast, difference coding of video images provides a constant verification of either the presence or absence of changes in the

system's state. Under new DOE guidance on the use of "alternative security measures," the EIVSystem qualifies to reduce the required frequency of physical inventories and is instrumental to the DOE policy of keeping the radiation exposure of personnel as low as reasonably achievable.

Data from the EIVSystem cameras installed in a vault or storage area are transmitted by means of fiber optic cable to a safeguards office complex. There they are processed by the host computer, analyzed for events, and if an event is detected, it is video recorded using wavelet transform image coding. The data are reviewed weekly by safeguards personnel to determine if any detected events have safeguards significance. Figures 5a, 5b, and 5c show events detected by the EIVSystem.

In Figure 5a, scenes from before and after legitimate maintenance access to the vault are analyzed. (A maintenance access is for servicing security or other equipment; no access to stored items is authorized.) The top image represents the vault before access; the middle image represents the vault after the access; the "difference" data show that an unauthorized access or movement was made to one of the drums in storage. Figure 5b shows a detected event without safeguards significance: the doors of the vault being opened by security personnel for an alarm check. Figure 5c shows data detecting the removal of a drum from the vault. In all cases, detected events trigger the storage of wavelet coded video and may send an alarm to a central alarm station.

Fig. 5a. Before (top) and after (middle) images from the EIVSystem show the movement of a drum (bottom) that may indicate tampering or a theft of material.

Fig. 5b. Difference data detecting the vault doors being opened for an authorized alarm check.

b. Video Time Radiation Analysis Program.

VTRAP is designed to compile data from numerous sensors—including gamma or neutron detectors, motion sensors, and video systems—and use neural network and pattern recognition methods to do the following:

- correlate large quantities of diverse information;
- identify abnormal activity, such as diversion of material or faulty data from intermittent sensors;
- develop inferences and conclusions;
- increase safeguards efficiency by routinely analyzing all data, identifying specific trends and flagging data to be checked, and relieving the tedium of reviewing masses of information; and
- automatically verifying plant operation and storage areas.

A simple example is illustrated in Fig. 6. Two radiation detectors and a video camera are installed at a facility to monitor process events. A normal event consists of a technician removing some nuclear material from a vault, walking past a radiation detector, and depositing the material in a neutron counter. The technician then removes the material from the counter, walks back past the detector, and returns the material to the vault. The spikes in the center of Fig. 6 represent the data gathered by each sensor.

First the figure shows a video spike where the technician enters the area, next a neutron detector spike appears as the technician walks past, then a neutron counter spike appears when the material is deposited into the neutron counter, and finally neutron detector and video spikes show up as the technician returns the material to the vault.

The data are correlated and a visual picture of a normal process event is quickly displayed to the inspector, saving the time it would take to review each instrument's data separately and draw a conclusion.

Although continuous, unattended radiation and surveillance monitoring systems can significantly reduce inspector time in facilities, they do produce large amounts of data that must be stored for the duration of the inspection period. Thus, appropriate compression methods applied to the data become critical to the success of such systems. (See Part 1, Sec. I.G.2 for a description of the VTRAP experimental setup.)

C. Nondestructive Assay (NDA) Measurement Technology

The objectives of this task are to develop and adapt state-of-the-art NDA techniques and instruments to meet the needs of DOE and commercial nuclear facilities, as well as those of safeguards inspection authorities, for materials control, accountability, and inventory verification. The objectives also encompass developing new NDA techniques that provide safeguards against insider threats and that meet the need for near-real-time accountability of new material types encountered in a reconfigured complex and resulting from weapons dismantlement.

1. Neutron Generator: Combined Neutron/Gamma-Ray and Spent Fuel Assay (M. M. Pickrell, NIS-5). We have assembled a complete experimental apparatus around the novel EMR/Schlumberger 14-MeV neutron generator.¹¹ The Schlumberger system provides consistent and reliable operation and flexible control that allows exploration of several new safeguards approaches. Two ideas that have been investigated using this system are the measurement of spent fuel using active neutron interrogation and the measurement of matrix constituents by neutron-induced gamma-ray spectroscopy.

The experimental system integrates data acquisition and neutron generator control using a PC as a controller. The computer enables, runs, and shuts down the neutron generator gracefully, following the Schlumberger operating procedures. It also provides diagnostic monitoring, interlock, and safety control. Finally, the system controls the neutron pulse width and frequency, within the Schlumberger-prescribed limits.

The data acquisition component consists of gated neutron counters, gated multiplicity counters, and two channels of multichannel-in-time counters. The multichannel time counters count discrete neutron pulses in successive time bins. The size of the time bins can be programmed from the computer (4 microseconds to 30 minutes) as can the number of bins (4 to 4096). All of the data acquisition is synchronized with the neutron pulse. All measurement and control parameters are programmed by the computer control software, including the neutron pulse frequency, the neutron pulse width, the number of neutron pulses to

Fig. 5c. Difference data (top, left to right) detecting access to the vault and subsequent removal of a drum.

run, start and stop gate times for the multiplicity counter, start and stop gate times for the neutron counter, and the number and widths of the time bins for the multichannel time scalars.

In addition, we have interfaced a high-resolution gamma-ray spectroscopy system to the neutron experiments. The gamma-ray data acquisition is also gated on and off under computer control and is synchronized with the neutron pulses. The output from a high-resolution, high-purity germanium (HPGe) detector is recorded on a MCA for spectral interpretation. Gamma-ray peaks from both thermal neutron absorption and inelastic scattering are observed.

The first active neutron concept that we are investigating is the measurement of the fissile material content of spent fuel. The present technique for assaying spent fuel is an indirect measure of the fissile material content. The assay is a passive measurement of the fission products in the spent fuel, from which the fuel burnup is inferred. The fissile material is then inferred from the assumed fuel history and composition and the inferred burnup value.

We are investigating a novel active system that measures the fissile material directly using active neutron interrogation by the Schlumberger neutron generator. The technical challenges for this system are separation of the fission neutrons from the interrogating neutrons, separation of the

fission neutrons from the high ambient background neutrons, interference from the large gamma-ray background, ensuring that ^{235}U and ^{239}Pu are the dominant source of fission neutrons (rather than ^{238}U , which can be fissioned by energetic neutrons), and ensuring that the interior fuel rods are sampled nearly equally with the outer rods.

We call our approach to solving these problems the Synchronous Active Neutron Detection (SAND) system. The SAND system separates the neutrons in frequency and phase rather than in time. The basis for the measurement is essentially the measurement of the $k_{\text{effective}}$ of a subcritical assembly using reactor noise analysis techniques. The multiplication factor $k_{\text{effective}}$ is directly proportional to the fissile material in a fixed subcritical assembly.

Initial results look quite promising. For example, Fig. 7 shows the response of this system as a function of the number of fuel rods (fresh fuel) in a test assembly. Rods from different locations were swapped in and out. The response of the system is linear with the number of fuel rods (that is, with fissile material) and largely independent of fuel rod position.^{12, 13}

2. Improving the Accuracy of Shuffler Assays of 208-L Waste Drums (P. M. Rinard and T. H. Prettyman, NIS-5). The largest source of inaccuracy in

Fig. 6. Data collected from multiple safeguards instruments are correlated and analyzed to detect anomalous activities at a nuclear facility.

shuffler assays of 208-L waste drums arises when the matrix is moderating (hydrogen density greater than 0.003 g/cm^3).¹⁴ The neutron transport is affected and the fission rate depends on the position of the uranium in the drum. When the hydrogen density is greater than 0.003 g/cm^3 but less than 0.01 g/cm^3 (as is true for matrices of paper and most matrices of rubber and plastic) and self-shielding is not a problem, a sleeve of polyethylene can be placed over the drum to reduce the energy of the irradiating neutrons; the accuracy is greatly improved.¹⁴

When the matrix is significantly moderating and the sleeve may induce excessive self-shielding, the accuracy of the shuffler can be improved with a more detailed analysis of the count rates from the individual detector banks surrounding the assay chamber. If the radius and height of the uranium within the drum can be determined from these data, a correction factor for that position can be applied.

Three techniques for finding the uranium's position have been studied.¹⁵ The first technique uses the variations in the detector-bank count rates as the drum continuously rotates. The second approach takes data from four fixed orientations of the drum relative to the irradiating source and uses reconstruction algorithms to create a medium-resolution image of the uranium's position. The third technique uses the same data as the second, but analyzes them with neural networks to obtain the uranium's position.

Each technique has now been studied individually. The next step is to better understand the strengths and weaknesses of each and to begin applying one or more techniques to actual shufflers.

3. Test and Evaluation (T&E) of the Tomographic Gamma-Ray Scanner (TGS) Prototype (G. A. Sheppard, T. H. Prettyman, and E. Adams, NIS-5; R. J. Estep, NIS-6; S. E. Betts, CST-7). We have fabricated, assembled, and electromechanically tested our prototype TGS. Limit switches and other safety devices have been installed and tested, and a Plexiglas cage was erected around the TGS to restrict personnel access and reduce the hazards due to moving parts and radiation exposure. The safety devices and cage eliminated the need for a standard operating procedure (SOP) specific to the TGS.

We used the prototype TGS to assay more than one hundred 208-L test drums containing both plutonium and uranium. The drums were configured to simulate conditions that we expect to encounter in the assay of transuranic (TRU) waste, and a variety of matrix types were used. Drums containing sand and dirt were used to simulate sludges. We used a variety of drums containing nonuniform matrices to test the capability of the TGS to correct for matrix heterogeneity. Low-density homogeneous drums were also included. Different emission distributions were

Fuel Bundle Response Test

Fig. 7. Response of the SAND system as a function of the number of the fuel rods in an assembly.

simulated using several plutonium sample sets. Four segmented gamma-ray scanner (SGS) standards with ^{239}Pu masses ranging from 10 to 100 g were scanned in drums bearing heterogeneous matrices to test the ability of the TGS to correct for combined matrix and source inhomogeneities. The average bias for plutonium assays using the 414-keV line was less than 2%, with a distribution standard deviation of 10%.

The TGS team also worked with the Los Alamos Waste Management Group to transfer a set of 32 TRU drums from Rad-Waste Operations at Los Alamos Area G to the TGS staging area. The 32-drum set was selected from the Waste Management database to represent both routine and challenging assay conditions. The net density of the drums ranged from 0.15 to 0.5 g/cm³, and plutonium loadings ranged from 1 to 165 g of ^{239}Pu . The results of this study will be a useful resource for planning the measurement campaign for the state-mandated TRU-waste remediation project that is scheduled to begin in FY 1995. We are developing a mobile TGS to be deployed at Area G for this project. [Funding for the mobile TGS was provided by the Los Alamos Environmental Systems and Waste Characterization Group (CST-7).]

Our 32-drum study resulted in the first measurements of TRU waste ever made using computerized tomography.

Emission and attenuation images of a selected TRU drum are shown in Fig. 8. Reconstructed three-dimensional images can be rendered as radiographs. The image on the left is a radiograph of gamma-ray-attenuating material within the drum. The image on the right is a radiograph of the distribution of emitting material within the drum. With a scientific workstation, the orientation of the drum relative to the observer can be selected. The drum contents can also be put into motion to help visualize the relative position of important features. Other methods of image rendering, including section images and side-view radiographs, can be used to precisely determine the position of radioactive material within the drum. Most of the drums examined in this study were found to be highly heterogeneous.

4. Data Analysis and Modeling Algorithms for Tomographic Gamma Scanning (T. H. Prettyman and R. A. Cole, NIS-5). Over the past year, we have made significant progress in developing modeling and analysis techniques for low-resolution, quantitative computerized tomography (CT). The unique application of CT to the radioassay of bulk samples has driven some new innovations in the field of tomography. For example, we have developed a new class of emission tomographic reconstruction algorithms for NDA with high-resolution gamma-ray

Fig. 8. TGS images of the contents of a 208-L drum containing TRU waste are displayed as radiographs. The left radiograph shows the distribution of attenuating material within the drum (dark regions are more highly attenuating). The right radiograph shows the distribution of emitting material (in this case ^{239}Pu) within the drum (dark regions contain more emitting material). The drum is rotated so that the observer is looking through the top of the drum.

spectroscopy (HRGS).¹⁶ These algorithms are formulated using a maximum-likelihood approach in which the statistical structure of both the gross and continuum measurements used to determine the full-energy response with HRGS is modeled. These algorithms can be applied to safeguards and environmental assays of large samples where high continuum levels caused by Compton scattering are routinely encountered. Using numerical modeling, we have found that the new algorithms outperform conventional reconstruction techniques when the statistical quality of the HRGS measurements is poor (for example, low full-energy counts in combination with high-background-continuum levels). Use of the new algorithms is expected to significantly reduce the quantification limits of emission tomography for safeguards and waste assay.

Central to our analytical capability is the TCNDA code (for Transmission-Corrected Gamma-Ray NDA). TCNDA is a modular code system that is being applied to study TGS, SGS, and intermediate gamma-ray scanning protocols. Current TCNDA features include¹⁷

1. a finite-elements model of the sample with arbitrarily shaped voxels to accurately model sample shape and contents,
2. conformal mapping procedures to generate grid points for the finite elements model based on transmission images and *a priori* information about sample shape,
3. the capability to merge combinatorial geometry models with a 3-D computational grid to include *a priori* information about sample geometry and composition (for example, container shape and composition),

4. a general-geometry Monte Carlo model of the spatial response for general collimator/detector designs (particularly important for asymmetric spatial responses encountered in the variable geometry collimator),
5. limited data transmission reconstruction algorithms and nonlinear interpolation models to accurately determine attenuation images at the assay energies,
6. the new class of maximum-likelihood emission reconstruction algorithms for quantitative assays with HRGS, and
7. preliminary algorithms to estimate assay precision (includes lump corrections).

TCNDA was developed to run in a UNIX workstation environment. Specific modules, including the emission matrix generator and several of the image rendering routines, are run in parallel on heterogeneous workstation clusters and parallel computers under parallel virtual machines. Fault tolerance and dynamic load balancing are standard features of the parallel modules. The computational speed provided by the parallel environment allows us to explore rapidly the effect of system design and the selection of analysis techniques on the quality of the assay result.

At present, TCNDA is used as a research tool and is not well suited for use by the neophyte gamma-ray analyst. Modules from TCNDA will, however, form the basis for analysis and rendering engines of future TGS systems. In delivered systems, specific TCNDA modules will be controlled using a windows-based PC interface that is customized for the user's application.

5. Gamma-Ray Assay: Lump and Matrix Corrections in SGS Drum Measurements (G. A. Sheppard, T. H. Prettyman, J. K. Sprinkle, Jr., and E. C. Piquette, NIS-5). We used the TGS to investigate the performance of an advanced lump-correction algorithm for gamma-ray assays of plutonium. A set of standards consisting of small vials, each filled with approximately 2 g of ^{239}Pu , was used to simulate lumps (the level of self-absorption by the vials at 413.7 keV was approximately 30%). We distributed the vials within 208-L drums containing low- and medium-density, heterogeneous matrices. An algorithm to correct for self-attenuation (the lump-correction) was then applied to both TGS and SGS assays of the 208-L mock-ups. When applied to the TGS assays, the lump-correction was found to be effective. However, the correction failed when it was applied to SGS assays of drums with heterogeneous contents.

By means of additional experimentation, we directly linked the failure of the lump-correction algorithm to determine the level of self-absorption accurately using the results of SGS to energy variations that are independent of the lumps. Additional sources of bias in SGS assays, such as heterogeneity in the matrix, can cause energy variations in the assay result. Hence, the observation of increasing assay mass with energy does not necessarily mean that lumps are present. However, the additional sources of bias cause energy variations in the assay results that differ substantially from those caused by lumps. As a result, failure of goodness-of-fit metrics (for example, reduced chi-squared) can be used to flag SGS assays that suffer from bias caused by gross spatial heterogeneity.

This result has considerable significance for hybrid gamma-ray scanning where high throughput can be achieved in SGS or far-field mode. For example, information from real-time radiography, drum weight, and SGS lump-correction flags can be combined to identify samples that require more time-consuming TGS assays. As a result, the overall throughput of such a system can be increased without sacrificing accuracy.

Preliminary results from the lump-correction study and from an earlier study of data correlations between adjacent SGS segments were presented in 1994 at the INMM Annual Meeting.^{18, 19} We plan to incorporate the new lump-correction and correlated-segment correction algorithms into the Automated Retirement and Integrated Extraction System (ARIES) SGS software and further evaluate them at the Los Alamos Plutonium Facility (LAPF).

6. Weapons Dismantlement NDA System (T. E. Sampson, M. S. Krick, G. A. Sheppard, W. J. Hansen, W. C. Harker, C. M. Schneider, G. Walton, and P. Collinsworth, NIS-5; T. A. Kelley, CIC-12; T. L. Cremers, NMT-4). ARIES is a program to demonstrate automated dismantlement of nuclear warhead components and recovery of the SNM in an unclassified form suitable for storage. The Los Alamos Safeguards Assay Group is responsible for demonstrating a robotically operated suite

of four NDA instruments, contained in a glovebox environment, that will assay the SNM content of all outputs of the dismantlement process. The characteristics of the four instruments (calorimeter, plutonium isotopic analysis, SGS, and neutron coincidence counter) and the NDA Host Computer have been described previously.²⁰

Although the overall pace of the project slowed somewhat during FY 1994 because of a redirection of funding priorities (the principal funding sponsor is the DOE Stockpile Support program), we made significant progress on the design and fabrication of the components of the ARIES NDA system. The ARIES neutron coincidence counter has been completed and is undergoing testing. Fabrication of the SGS and the Fixed Energy Response Function Analysis with Multiple Efficiency (FRAM) plutonium isotopic analysis system is 85% complete. The calorimeter, fabricated by EG&G Mound Applied Technologies is scheduled for delivery in early 1995. Software development for the four NDA instruments and the host computer is underway. We are planning a demonstration of the integration of the NDA instruments, host computer, and robot in a mockup glovebox environment at the end of FY 1995.

The completed ARIES coincidence counter, shown in Fig. 9, is built in a clamshell arrangement to fit around a well projecting from the bottom of the glovebox.

D. Computational Physics and Simulation for NDA Technology Development

The goals of this task are to develop computational physics, mathematical simulation capabilities, and physics analysis algorithms to improve NDA techniques for measuring nuclear materials. The goals include improving near-real-time materials control and accounting (MC&A), reducing the design cost of NDA instruments, extending assay capabilities to other SNM categories, and developing better diversion detection algorithms. Because computational physics activities support new developments in detection and NDA technology, activities in this task will continue to evolve rapidly as new NDA techniques, instruments, and measurement needs are defined by other tasks.

1. Neutron Detector Optimization for 208-L Drums (H. O. Menlove, D. H. Beddingfield, and M. M. Pickrell, NIS-5). For safeguards related to facility clean out and waste removal, it is necessary to measure the plutonium content and to verify that there is no shielding material present that could mask larger quantities of nuclear material in the waste storage drums. Our developments to address these problems include the add-a-source technique²¹ to characterize the matrix and passive neutron multiplicity counting to identify localized shielding of plutonium inside the drum.

Multiplicity counting requires highly efficient detectors to give reasonable statistical results. We are using Monte Carlo neutron and photon (MCNP)²² calculations

Fig. 9. Assembled ARIES coincidence counter.

to design a high-efficiency 200-L-drum counter. Both cylindrical and cubical sample cavities are being evaluated. The preliminary results for a cylindrical design with two rings of 1-in.-diam. ^3He tubes (4 atm pressure) are shown in Fig. 10. The total efficiency reaches 40% for the no-cadmium case and 34% for the case with a cadmium liner on the sample cavity. The efficiency for spontaneous fission neutrons is higher for ^{240}Pu than for ^{252}Cf because the ^{240}Pu has a lower average energy for its neutron spectrum.

We are using the MCNP calculations to evaluate the ^3He tube spacing, pressure, diameter, reflectors, and moderator materials. The final design will be used to build an advanced neutron counter for 200-L drums.

2. Monte Carlo Simulation of Active Well Counter Design for UF_6 Cylinders (T. R. Wenz, H. O. Menlove, G. Walton, and J. Baca, NIS-5). We have

modified an active well coincidence counter²³ (AWCC) to measure the uranium content of highly enriched uranium (HEU) hexafluoride (UF_6) stored in cylindrical bottles. The cavity height in an AWCC with standard end plugs is 20 cm, but the length of the active volume in the bottles is approximately 40 cm. This measurement required designing new inserts for an existing AWCC to optimize the counting response over the active region of the storage bottles. The design calculations were performed using MCNP,²⁴ a Monte Carlo transport code developed at Los Alamos, because the difficulty in obtaining and fabricating UF_6 calibration samples limits the number of experimental measurements. Also, the Monte Carlo calculations permit greater flexibility in material selections and geometry configurations.

We used three principal criteria in designing the UF_6 inserts for the AWCC: (1) a uniform detector response over

Tube Depth Optimization for Two Ring Barrel Counter 40 1 inch ^3He tubes/row at 4 atm gas pressure Inner tube ring diameter is 33.54 cm

Fig. 10. MCNP calculations showing detector efficiency as a function of ^3He tube spacing in the cylindrical polyethylene moderator for a 200-L-drum counter. The counter contains two rings of tubes with 40 tubes per ring.

the active region of the UF_6 bottles, (2) an increase in the overall response of the detector per gram of material measured, and (3) a minimum error associated with the measured reals rate.

Calculations were made for cylindrical inserts composed of graphite, polyethylene, and a mixture of the two materials. The absolute reals count rates for each of the insert designs are shown in Fig. 11. The count rates are plotted as a function of location in the detector and are based on a fixed source strength from four AmLi sources. Four AmLi sources were used in the design of the insert to uniformly cover the UF_6 active region without using a scanning procedure. The "graphite-poly band" design consists of two rings of polyethylene replacing graphite at the location of the inner two AmLi sources. This is a multi-sectional insert design with alternating layers of graphite and polyethylene. The "graphite-poly cylinder" case is for an insert composed of graphite; the AmLi sources were placed in polyethylene bottles approximately 0.5 cm thick. This

configuration resulted in the highest response and was chosen for the final design.

The final insert is made of graphite and accommodates four AmLi sources encapsulated in polyethylene cylinders. The graphite increases the measured response over the polyethylene case because there are fewer absorption events in the material. The polyethylene cylinders around the sources lower the neutron energy spectrum to further increase the fission rate in the sample. A graphite end plug is situated at the bottom of the sample cavity to position the cylinder and to reflect neutrons. A top end plug was omitted because of the height of the cylinders. The sample cavity is lined with cadmium to eliminate thermal neutrons from the interrogation. The totals and reals response profiles are shown in Fig. 12 for a representative UF_6 sample.

The design objective was to obtain a fast-neutron response profile that was within $\pm 10\%$ of the average and to maximize the counting efficiency at the bottom of the

Fig. 11. Absolute reals count rates for various UF_6 cylinder insert designs from Monte Carlo calculations.

cylinder where much of the UF_6 is expected to condense. These two objectives were achieved based on the Monte Carlo data in Figs. 11 and 12. Also, the relative error calculated with the Monte Carlo data decreased with the new insert design primarily because of the increased reals rate satisfying the error criteria.

E. Technology Development for Holdup, Confirmatory, and Inventory Verification

The objective of this task is to develop and document specialized instrumentation for in-plant holdup, waste, confirmatory, and inventory verification measurements to meet the needs of the reconfigured DOE complex for materials control, accountability, screening, or diversion detection information.

1. Multi-Position Add-a-Source Development (H. O. Menlove and J. Baca, NIS-5). Accurate pluto-

Fig. 12. Axial response profiles for the AWCC with the UF_6 cylinder insert from Monte Carlo calculations.

nium measurements are difficult for large containers such as 200-L drums that contain heterogeneous mixtures of scrap, waste, and matrix materials. We developed the add-a-source technique²¹ to make accurate corrections for different kinds of matrix materials that are contained in waste drums. We have enhanced the original add-a-source method with a multi-position (or segmented) ^{252}Cf source capability to give a more representative sample of the matrix material. In the current design, the source stops at three locations to sample the drum contents.

Software for the multi-position add-a-source has been completed and applied to the prototype system at the Los Alamos TA-55 facility.

2. Integrated Neutron/Image Monitoring System (H. O. Menlove, NIS-5; J. A. Howell, NIS-7; C. A. Rodriguez, NIS-7; and D. Beddingfield, NIS-5).

We have developed a new method to integrate radiation monitoring with digital video information. Los Alamos has long-standing development programs related to NDA radiation monitoring, video digital image processing, and neural network analysis. The new activity is a method to merge these three disciplines into an integrated monitoring system.

For the past several years, the integration of containment and surveillance (C/S) with NDA sensors for monitoring the movement of nuclear material has focused on the hardware and communications protocols in the transmission network. Little progress has been made in using the combined C/S and NDA data for safeguards and reducing the time inspectors spend in nuclear facilities. One of the fundamental problems in integrating the combined data is that the two methods operate in different dimensions; the C/S video data is spatial in nature, whereas the NDA sensors provide data on radiation levels as a function of time.

We have developed a new method to facilitate this integration of spatial and radiation time information, that is, to transform the video spatial data into the time domain as a function of physical motion in the video data. We call the method video time and radiation analysis program (VTRAP).²⁵ Every 1-5 s a video picture of the area of interest is compared with the baseline picture, and the quantitative amount of change or movement is converted to a single pixel difference number. This provides a data compression of $\sim 10^5$ and allows a comparison in time with the radiation sensors that are synchronized with the video motion data.

The short time intervals (1-5 s) give a continuity of knowledge that is not possible with normal collection of video data. In addition, the essentially continuous data collection avoids the problem of missing a crucial trigger event.

To develop the VTRAP concept, we set up combined video and radiation monitors in a nuclear materials laboratory at Los Alamos. The NDA radiation sensors include a neutron coincidence counter and a compact neutron detector positioned on the wall of the room. Each of these NDA

sensors has its own electronics and data collection software. The video camera is connected to a Sun Sparcstation to store and analyze data. The pixel difference numbers vs time are stored as well as full video images when pre-set thresholds are exceeded.

A typical neutron sensor is shown in Fig. 13 including a ^3He tube in a polyethylene moderator, a PDT-110A preamplifier, the portable shift register (PSR) electronics,²⁶ and a LON* module for connection to the data collection network. The PSR unit supplies the high-voltage bias, preamplifier power, and the data collection, coincidence logic, and data transmission capabilities to the collect computer.

To train the neural network, we defined a set of normal activities in the laboratory where nuclear material is removed from storage, placed in the neutron coincidence counter for measurement, and then returned to storage. The normal activities also include movement of people and equipment in the room with no movement of nuclear material. After the normal activity training period was completed, we provided the sensors with abnormal activities, such as removal of a radiation source from the storage vault and no returning of it to the vault.

Typically, there would be multiple (3-10) sets of video and radiation sensor data synchronized in time with coupled information related to the location, direction, and speed of motion of the nuclear material. Because of the complex relationships in the multiple integrated data sets, neural networks can be used effectively to evaluate the data. During times of abnormal activity, full (or compressed) video images are saved.

The VTRAP approach is well suited for large automated facilities where the movement of nuclear material is

restricted by the constraints in the robotics system. The VTRAP would also find applications at reactors, spent-fuel storage facilities, reprocessing plants, nuclear material storage vaults, and in the long-term disposition of surplus fissile materials.

3. Scintillator/Solid State Detector Technologies as Replacements for the Compact Sodium Iodide Detectors (P. A. Russo, M. C. Sumner, and D. A. Close, NIS-5). New technologies in room-temperature gamma-ray detectors are sought to improve the compactness, ruggedness, and energy resolution of the detectors yet maintain or improve upon their efficiency and reliability compared to the compact NaI(Tl)/photomultiplier tube (PMT) detectors developed at Los Alamos²⁷ and now available commercially. The crystal dimensions, operation, and performance of the compact NaI(Tl)/PMT detectors are summarized in Tables I and II. Better and smaller detectors would make portable gamma-ray spectroscopy units easier to use and thus facilitate responding to regulatory requirements and nonproliferation needs. Figure 14 shows one example of the limitations of the current detectors. The four gamma-ray spectra obtained with the 5-cm-thick compact NaI(Tl)/PMT detector illustrate the increasing contributions of ^{241}Am and ^{241}Pu (dominating the activity in the 300- to 375-keV intensified region) to the net count rate in the adjacent ^{239}Pu assay region at 375-450 keV as burnup (indicated by the ^{240}Pu fraction) increases. Improving the detector's energy resolution addresses this problem of bias.

After four decades of use, commercial alternatives to NaI(Tl)/PMTs for portable gamma-ray spectroscopy are just emerging. The ability to grow large solid-state crystals has evolved very slowly. Developments are also restricted by the intrinsic limitations in charge-collection properties of room-temperature solid state materials, constraining the useful thicknesses of crystals for gamma-ray spectroscopy.

*A product of LONWORKS PLC-10, Echelon Corporation, 4015 Miranda Avenue, Palo Alto, CA 94304.

Fig. 13. Schematic diagram of a neutron radiation sensor including the ^3He detector, a PDT110A amplifier, and the PSR coincidence electronics. The PSR has local data storage and 10-hr battery backup for power outages.

TABLE I. Characteristics of 5-cm-NaI(Tl)/PMT, HgI ₂ , and CsI(Tl)/HgI ₂ Detectors			
Detector	NaI(Tl)/PMT	HgI ₂	CsI(Tl)/HgI ₂ -PD
Diameter	2.5 cm	2.0 cm	1.3 cm
Thickness	5.0 cm	0.3 cm (0.6-cm NaI(Tl) equivalent ^a)	1.3 cm (1.6-cm NaI(Tl) equivalent ^a)
Bias	500 V	2500 V (low power)	2500 V (low power)
Amplifier T	0.5 μsec	~10 μsec	~10 μsec
FWHM, at 662 keV	7.7%	7.2%	4.9%
Status	commercial (Bicron Corp.) ^b	laboratory prototype (EG&G Santa Barbara) ^c	commercial prototype (Xsirius, Inc.) ^d
^a equivalent NaI(Tl) thickness for 400-keV gamma rays ^b Bicron Corp., 12345 Kinsman Rd., Newbury, OH 44065 ^c EG&G Energy Measurements, Inc., 130 Robin Hill Rd., Goleta, CA 93116 ^d Xsirius, Inc., 1220 Avenida Acaso, Camarillo, CA 93012			

Proposed solutions to these intrinsic limitations include new analog pulse-processing technologies to reject or compensate for defects in pulse heights as well as assemblies of multiple small-crystal components to minimize the defects. These solutions are major advances that require significant development and testing beyond that required for the solid-state room-temperature gamma-ray detectors. Two other, more promising solutions are described below. These benefit fully from the advantages of the larger room-temperature solid-state crystals without the need for multiple small-crystal components or added layers of complexity in pulse processing. Representative prototype detectors have been tested recently at Los Alamos, and collaborations with the DOE and commercial developers are underway.

a. Mercuric Iodide, HgI₂. For many years, HgI₂ has been under development as a solid-state room-temperature gamma-ray detector. We recently acquired a laboratory prototype HgI₂ detector, whose crystal size, operation, and performance are summarized in Table I, for comparison with the compact, 5-cm-thick NaI(Tl)/PMT detector. The energy resolution of the HgI₂ detector at 662 keV is slightly better than that of the typical compact NaI(Tl)/PMT detector. However, evidence of the intrinsic problems associated with the collection of charge is apparent in the asymmetry of the 662-keV peak and the significant low-energy tail between the peak and the Compton edge. The compact NaI(Tl)/PMT detector is a better choice than the

TABLE II. Status of 1.3-cm-NaI(Tl)/PMT, CdTe, and Cd(Zn)Te Detectors				
Detector	Manufacturer	Detector Dimensions		Status
		diameter	thickness	
NaI(Tl)	Bicron Corp.	2.5 cm	1.3 cm	currently in use
CdTe	Radiation Monitoring Devices, Inc. ^a	≤ 1 cm	0.2 cm	too small to be useful in this application
Cd(Zn)Te	eV Products/II-VI Inc. ^b	1.5 cm	0.4 cm	test results show promise; larger sizes are available
coplanar-grid Cd(Zn)Te	Lawrence Berkeley Lab/eV Products	1.5 cm	1.5 cm	commercial prototype on order
^a Radiation Monitoring Devices, Inc., 44 Hunt St., Watertown, MA 02172 ^b eV Products, a Division of II-VI Inc., 375 Saxonburg Blvd., Saxonburg, PA 16056

(a)

(b)

(c)

(d)

Fig. 14. Gamma-ray spectra of four plutonium oxide samples of a matched set with variable burnup or percentage of ^{240}Pu (a. 6.0, b. 19.8, c. 21.3, and d. 24.1) obtained with the compact NaI(Tl)/PMT detector. The shaded regions are 181-235 keV, 300-375 keV, and 375-450 keV (the "assay" region for ^{239}Pu).

solid state HgI_2 detector at this time because (1) the asymmetry and tailing are not features of NaI(Tl)/PMT spectra, (2) the efficiency for detecting 400-keV gamma rays is very low for the thin HgI_2 detector compared to the compact NaI(Tl)/PMT detector, and (3) the energy resolution is comparable for the two detectors,

The use of HgI_2 as a photodetector coupled to a CsI(Tl) scintillator has recently been tested in our laboratories and reported.²⁸ A commercial prototype of such a detector is described in Table I. The advantage of this HgI_2 approach is that only a minimal thickness of the solid state HgI_2 photodetector (less than 1 mm), sufficient to be opaque to the scintillation light, is required. Because of the maturity of the manufacturing technology for CsI(Tl) scintillator materials, there is no practical limitation on the size or shape of the crystal in which the gamma-ray interactions take place. The ^{137}Cs gamma-ray spectrum ob-

tained with the commercial prototype CsI(Tl)/ HgI_2 detector (Fig. 15) shows that the gamma-ray energy resolution is 4.9% at 662 keV, two thirds of the resolution of the compact NaI(Tl)/PMT detectors. The CsI(Tl)/ HgI_2 gamma-ray spectra are Figs. 16a and 16b, respectively for the same low-burnup plutonium sample used to obtain the Fig.-14a spectrum (Fig. 16a) and the high-burnup plutonium sample used to obtain the Fig.-14c spectrum.

The advantages of CsI(Tl)/ HgI_2 for NDA of nuclear materials is easily seen by comparing the plutonium spectra in Figs. 14 and 16. A detector built with the CsI(Tl) crystal, equivalent in size and gamma-ray detection efficiency (at 400 keV) to the compact NaI(Tl)/PMT detector would be about one half the overall size of the NaI(Tl)/PMT detector, a great advantage for portable gamma-ray spectroscopy. Although no additional analog pulse-processing technologies are required, the need for a longer

Fig. 15. Gamma-ray spectrum of ^{137}Cs obtained with the commercial prototype HgI_2/PD detector.

amplifier shaping time than that required by the $\text{NaI}(\text{TI})/\text{PMT}$ detectors requires a modification to the existing portable gamma-ray spectroscopy systems and imposes a limitation on the applications to low-count-rate measurements. Further testing of larger commercial prototype $\text{CsI}(\text{TI})/\text{HgI}_2$ detectors is planned.

b. Cadmium (Zinc) Telluride, $\text{Cd}(\text{Zn})\text{Te}$.

Although CdTe detectors for spectroscopy have been available for more than a decade, the crystals cannot yet be made large enough to replace 1.3-cm-thick compact $\text{NaI}(\text{TI})/\text{PMT}$ detectors. However, recent advances in $\text{Cd}(\text{Zn})\text{Te}$ materials technology have resulted in the ability of one manufacturer to grow larger, spectroscopy-grade crystals. Table II provides information on the CdTe and $\text{Cd}(\text{Zn})\text{Te}$ detectors for comparison with the 5.0-cm-thick compact $\text{NaI}(\text{TI})/\text{PMT}$ detectors. The $\text{Cd}(\text{Zn})\text{Te}$ detector described in Table II has been tested recently at Los Alamos. Figure 17 shows superimposed, gain-matched spectra of a ^{235}U sample obtained with identical counting times and measurement geometries using the 1.3-cm compact $\text{NaI}(\text{TI})/\text{PMT}$ detector and the $\text{Cd}(\text{Zn})\text{Te}$ detector. The counts in the $\text{Cd}(\text{Zn})\text{Te}$ spectrum are multiplied by 10 to normalize the spectra at 186 keV. The improved resolution of the $\text{Cd}(\text{Zn})\text{Te}$ detector is apparent at 186 keV and also in the appearance of the 205-keV peak that is not resolved in the $\text{NaI}(\text{TI})$ spectrum. However, $\text{Cd}(\text{Zn})\text{Te}$ gamma-ray peaks exhibit a pronounced asymmetry that results from incomplete charge-collection effects. The order-of-magnitude-lower detection efficiency at 186 keV includes a factor of 5 for the smaller diameter/thickness of the $\text{Cd}(\text{Zn})\text{Te}$ crystal. The rest is assumed to be related to charge-collection problems. The manufacturer now

produces larger diameter/thickness crystals, but increased thickness will worsen the asymmetry problems.

A completely new technology that uses surface strip (grid) electrodes to effect single-carrier charge collection has recently been developed with thicker $\text{Cd}(\text{Zn})\text{Te}$ (as indicated in Table II) from the same manufacturer. These coplanar-grid $\text{Cd}(\text{Zn})\text{Te}$ detectors have been demonstrated and reported.²⁹ The technology, which is elegant in its simplicity, gives remarkable results in terms of eliminating the asymmetry in the gamma-ray peak shapes. It enables use of the thicker (as well as larger-diameter) crystals with the corresponding increase in detection efficiency and, simultaneously, a dramatic improvement in spectrum quality. We are procuring such detectors.

F. Chemical and Isotopic Measurement Technology

Chemical analysis methods provide the reference base for materials accounting and product quality assurance in the nuclear industry. In this task, we develop new, highly reliable methods of chemical analysis for the determination of plutonium and uranium in all varieties of nuclear fuel-cycle materials with emphasis on automated chemical analyzers to improve turnaround time and reduce analyst bias and error. Developing and refining this technology for the wide range of plutonium and uranium compositions is essential to achieve timely, accurate safeguards accounting.

Plutonium Assay Based on $\text{Pu}(\text{VI})$ Spectrophotometry (L. F. Walker, D. J. Temer, and D. D. Jackson, CST-8). We have developed a sensitive, selective method for plutonium assay based upon the sharp plutonium (VI)

Fig. 16a. Gamma-ray spectrum of the low-burnup-plutonium (6.0% ^{240}Pu) sample (sample a from Fig. 14) obtained with the laboratory prototype CsI(Tl)/HgI_2 detector. **16b.** Gamma-ray spectrum of a high-burnup-plutonium (21.3% ^{240}Pu) sample (sample c from Fig. 14) obtained with the laboratory prototype CsI(Tl)/HgI_2 detector.

absorption peak at 831 nm. The absorbance is sensitive to temperature, acidity, and nitrate concentration, so for best precision, these variables must be closely controlled. Constant temperature is easily maintained using a temperature-controlled cell. The acidity and nitrate content in the samples must be controlled or measured and the absorbance corrected. Preliminary measurements of the effect of acidity indicate a change of 0.1 M in nitric acid concentration causes about a 0.4% change in absorbance. The method is simple, rapid, and sensitive and is intended primarily for

use with plutonium nitrate systems. For most of the work, the acidity was adjusted to 2 M nitric acid prior to oxidizing the plutonium to (VI) with ceric solution. Because the absorption peak at 831 nm is very sharp, performance characteristics of the spectrophotometer are important. We evaluated a Hewlett Packard (HP) 8452 diode array instrument with a tungsten lamp option covering the spectral range of 470-1100 nm with a fiber optic attachment from Custom Sensors & Technology designed for use with the HP instrument. The attachment replaces the cell holder

Fig. 17. Gamma-ray spectra of a ^{235}U sample obtained with identical count times and geometries using the Cd(Zn)Te and compact NaI(Tl)/PMT detectors listed in Table II. The Cd(Zn)Te spectrum counts are multiplied by 10 for normalization.

and allows use of fiber optics with the HP spectrophotometer. The resolution of the HP8452 instrument was not adequate for the very sharp Pu(VI) peak. We are using a Guide Wave Model 260 scanning spectrophotometer with fiber optic coupling to a temperature controlled flow cell. With the present configuration, the method is best suited for samples in nitric acid with plutonium concentrations from 1 to 100 g/L and gives a precision of better than 0.3% RSD over most of this range. We demonstrated that the anions fluoride, phosphate, and sulfate at levels expected in nitrate process streams do not interfere with the plutonium measurement. No interference was observed at fluoride levels up to 0.1 mmole or phosphate and sulfate levels up to 0.04 mmole. We also conducted an interference study to investigate the effect of selected cations on the plutonium measurement. We selected eleven metals for testing; metal ions expected to be present in nitrate processing streams. The metals tested were aluminum, iron, sodium, magnesium, manganese, nickel, chromium, zinc, molybdenum, copper, and uranium. Each metal was tested individually by adding it as the nitrate salt in 2 M nitric acid solution. The initial test was at a metal-plutonium mole ratio of 10:1; metals interfering at this level were tested at a mole ratio of 1:1. Interference is defined as a change significant at the 95% confidence level relative to plutonium alone. Only copper and manganese interfere at the

10:1 mole ratio giving a slight negative bias. Copper had a spectral interference which was not adequately corrected with the baseline correction. Manganese formed a dark brown precipitate which slowly settled out leaving a dark red solution. Manganese also interfered at the 1:1 level with a slight positive bias; as at the higher level, a precipitate formed. Manganese did not interfere at the 1:10 level. None of the metal ions tested interfered at levels expected to be present in nitrate processing streams. Three samples of nitrate solutions from the cascade dissolver system at the plutonium processing facility containing high levels of iron, calcium, chromium, and nickel impurities were successfully measured by this method. We are continuing to evaluate the method and develop appropriate instrumentation.

G. Materials Accounting Information Systems: Automated MC&A Technology

Increasing amounts of nuclear materials within the DOE weapons complex, including materials from dismantled weapons and wastes and residues to be processed for disposal, produce a continuing need for improved systems to account for these materials. Developments in this task provide the DOE complex with technology for designing and implementing efficient, cost-effective, automated,

accurate database collection and information management systems. The task emphasizes development of the computer information processing technology necessary to accommodate the increased data processing needs of modern integrated safeguards systems.

1. Local Area Network Materials Accountability System (LANMAS) Technological Innovations (J. Claborn, E. A. Kern, and M. J. Roybal, NIS-7; M. Boor, CIC-12). LANMAS core software will provide the framework of a materials accountability system. LANMAS is a network-based nuclear material accountability system. It tracks the movement of material throughout a site and generates the required reports on materials accountability. LANMAS will run in a client/server mode. The database of material types and locations will reside on the server, whereas the user interface runs on the client. The user interface accesses the server by means of a network. The LANMAS core can be used as the foundation for building required MC&A functionality at any site requiring a new MC&A system. An individual site will build on the LANMAS core by supplying site-specific software.

Westinghouse Hanford Corporation (WHC) and Los Alamos National Laboratory began developing LANMAS in 1991. This collaboration produced the architecture and foundations used in the Sandia National Laboratories-Albuquerque (SNLA) LANMAS, which was implemented at SNLA in 1994. Los Alamos has been funded by DOE/Office of Safeguards and Security (OSS) to develop a core LANMAS.

Project Lifecycle. We have adopted the following software lifecycle model for the development of LANMAS.

- **Requirements Phase.** In the requirements phase the software development is planned and the requirements are defined and documented. Requirements are gathered from the various DOE Orders, particularly 5633.3B, 5633.4, and 5633.5. Requirements are also gathered from discussions with the various DOE sites. To date, discussions have been held with materials accountability personnel at the Westinghouse Savannah River Company (WSRC) Pantex, Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory, SNLA, Oak Ridge Y-12 plant, WHC, and Lawrence Livermore National Laboratory (LLNL). The software development plan is documented in the LANMAS Software Project Management Plan.³⁰ The software requirements are documented according to Institute of Electronics and Electrical Engineers (IEEE) Standard 830-1984, *Guide to Software Requirements Specifications*.³¹ The

first draft of the Software Requirement Specifications was released in June 1994. The initial release of the Software Requirement Specifications is currently awaiting approval signatures.

- **Design Phase.** During the design phase, the requirements are expanded into a system design that addresses each of the requirements. The design specifies the working plans for the various software components, interfaces, functions, data structures, and data flows. The design phase is aided by the creation of a prototype that clarifies the requirements. The design phase is divided into a preliminary design and a detailed design that further refines the preliminary design. The design is documented in the Software Design Description.³² It will be documented according to IEEE Standard 1016-1987, *Recommended Practice for Software Design Descriptions*.³³ The initial draft of the Preliminary Design³⁴ was released in September 1994.
- **Code Phase.** The code phase includes the transformation of the software components identified in the design phase into coded, tested units. The various components are assembled into an integrated system.
- **Testing Phase.** During the testing phase the integrated system is evaluated to determine whether or not the requirements have been satisfied. The testing is documented in a test plan results document. LANMAS testing will be documented according to IEEE Standard 829-1983, *Standard for Software Test Documentation*.³⁵
- **Installation Phase.** The software is implemented at a customer site. It is again tested to ensure that it performs as required. Each site tailors the LANMAS core to address their site-specific requirements.

LANMAS Typical Hardware Environment. The initial release of the LANMAS core will use computing environments that run Microsoft Windows 3.1 (or later), Microsoft Windows for Workgroups, and Microsoft Windows NT.

Major Milestones. Major milestones include completing the following:

- Functional System Requirements Document
- Software Project Management Plan Document
- Software Requirements Specification Document
- Software System Test Plan

- Software Design Document
- Software Code
- Software System Test

Current Status. The Functional System Requirements Document is in its first release. The Software Project Management Plan is also in its first release. The Software Requirements Specification initial draft was completed in June 1994. The contract to develop and perform the Software System Test Plan is being negotiated with an outside firm. The initial draft of the Software Design Document was released in September 1994. The initial release of the Software Code (ready for test) will be in July 1995. The project will be ready for delivery in October 1995.

Core Functionality. The LANMAS core will include the following functions:

- Material movements, external shipments and receipts
- Modifications/Adjustments - splits, combines, decays, and project number changes
- Containerization of items
- Nuclear Material Management Safeguards System reporting
- Physical inventory support functions
- Standard and ad hoc queries and reports
- Complete item transaction history
- System maintenance and administration functions
- On-line user help functions

Core And Site-Specific Relationship. An individual site will build on the LANMAS core by supplying site-specific software. Site-specific software will interface with the LANMAS core through the LANMAS core database and by invoking LANMAS core user-interface routines.

Major Components and Interfaces. A materials accountability system built on the LANMAS core will consist of the following major components.

- Site-Specific MC&A Software. This software is developed by each site to account for the local work and business culture.
- User/Site-specific Database. This database supports the site-specific software.
- LANMAS Core User Interface Routines. This set of user interface routines is supplied with the core LANMAS. They may be used as is, invoked from site-specific software, or used as the basis for the site-specific software.
- LANMAS Core Database. This database supports the LANMAS core user interface routines.
- LANMAS Core Support Functions. These functions support the operation of the database.

Site-Specific Customization. When the LANMAS core is delivered to an implementing site, the LANMAS core project team will work closely with the LANMAS implementors at the site to customize the core for each site. This level of interaction can range from custom function development to educating the local implementors about LANMAS so they can develop site-specific functions. When the LANMAS core is delivered, a full set of documentation is included. In addition to the project documents mentioned earlier, the following are also delivered:

- LANMAS Security Requirements. This document describes the security requirements for a site implementing LANMAS.
- LANMAS User Interface Developer's Guide. This document describes the method and style for producing LANMAS user-interface screens. By adhering to this guide, a site can incorporate site-specific functions that have the same look and feel as the core interface screens.
- LANMAS User's Guide. This document provides the user with the documentation needed to use LANMAS. It can be used as a starting point for developing a site-specific User's Guide.

2. ARGonne Unified Safeguards (ARGUS) Technology (J. E. Smith, NIS-7). ARGUS, a joint project of Argonne National Laboratory-West (ANL-W), Los Alamos, and SNLA, is an integrated materials accounting/materials control system that has been running since 1991 at the ANL-W Fuel Manufacturing Facility (FMF). The system uses a distributed database model to store the inventory on several computers in different areas in the facility, and near-real-time inventory updates are automatically sent between systems. The transaction logs are stored on a write once read many (WORM) optical disk system, mirrored offsite, which ensures data security and timely and accurate inventory reconstruction.

We participated in several new activities this year.

- Integrate Tamper-Indicating Device (TID) Tracking with ARGUS.** An additional database subsystem was added to ARGUS in this reporting period for TID tracking. TIDs can be added to the system or their records updated by the authorized TID custodian. Reports on TID status and location can be produced using the usual ARGUS reporting mechanism.
- Integrate Optical Disk Storage with ARGUS.** The ARGUS backup subsystem was updated to record the TID database on WORM storage monthly, as is now done with the SNM inventory and transaction log.

- c. **Integration of ARGUS with SNLA (PAMTRAK) System.** During FY 1994, the interface of the PC-Dynamic Materials Accounting (PC-DYMAC) system with the SNLA PAMTRAK material monitoring system was tested offline, then installed onsite at Argonne National Laboratory FMF. Barcode labels on containers and personnel badges are read by PAMTRAK and messages are sent to PC-DYMAC, where they are converted into transactions. Users are validated by the barcode reading system, matching the user(s) privileges with the type of transaction requested. In this way, transactions involving material movement and container changes are quickly and accurately entered into the accounting system.

3. Materials Accounting with Sequential Testing (MAWST) Windows (J. F. Hafer, NIS-7). The MAWST Windows project was conceived when WSRC was interested in IBM PC versions of MAWST. Two C Language versions were supplied to them last year: a disk version and a memory version. A Windows version for running MAWST was developed and sent to them this year. Their interest now is in a MAWST C code for the VAX that will eliminate some performance problems. A C MAWST code was provided to WSRC in April 1994. In February 1994 they requested the addition of menus and forms to make MAWST easier to run. WSRC is our main customer for MAWST. In addition, WSRC is seriously considering LANMAS to replace Nuclear Materials Accounting System (NucMAS). Variance propagation is planned for LANMAS in FY 1996.

Although an expanded Windows version of MAWST and a Windows version for building files may eventually be desired, we felt that the Windows work should be postponed. We replaced the MAWST Windows Project with modifications to the MAWST software system. These modifications will enhance WSRC support of MAWST and produce a MAWST code that should be usable by Nuclear Materials Accounting Limit of Error (NucMASloe). The major effort included the following:

- building input and output screens to facilitate MAWST processing;
- separating the measurement value file into four separate files for beginning inventory, receipts, removals, and ending inventory;
- modifying the structure of the DEFAULT.DAT file such that it can be associated with a facility; and
- implementing an inventory-difference-only calculation feature.

Descriptions of the input and the output were provided by WSRC along with the desired structure of the

DEFAULT.DAT file. The VAX Curses Library in VAX C is being used to produce VAX windows for input and output screens. Approximately 80% of the project is completed. The remaining work will be completed in the first quarter of FY 1995.

4. Acoustic Resonance Spectroscopy (ARS) Intrinsic Seals Software (C. T. Olinger, NIS-7). ARS has great potential to improve our ability to establish and monitor seals on SNM containers. An acoustic fingerprint can be made of an item for comparison with measurements to be made at later times to assure that no tampering has occurred. Comparisons are complicated by the fact that spectra are never truly identical and some regions in the spectrum can be adversely affected by benign activities. The main purpose of this task is to develop analysis and decision-making algorithms that will automatically determine whether or not tampering has occurred.

We have explored several algorithms for comparing ARS spectra. These included four similarity measures and two distance measures that compared spectra at each discrete frequency measured across the spectrum and one algorithm that only compares resonant frequencies. Most of these algorithms are adequate for distinguishing occurrence of tampering as well as whether the containers are in a favorable environment. However, if rooms undergo thermal cycling, containers are handled excessively, or care is not taken to exactly duplicate measurements (all of which we call nuisance effects), the ability to distinguish populations representing tampering from populations representing no tampering degrades (that is, the distance between populations is reduced).

If the data are smoothed across the spectrum, the algorithm that only looks for matches in resonant frequencies between the spectra appears to provide the best separation between the tamper and no-tamper populations. Data smoothing also appears to help in maximizing the distance between these populations when the containers are exposed to nuisance effects, but in extreme cases the populations still overlap. Figure 18 shows the difference in comparing populations using different algorithms. These plots overlay the populations representing no tampering but thermal cycling of the container from 22°C to 39°C and back to 22°C between measurements, the population where the container was opened between measurements, and a third population where the container was neither subjected to tampering or thermal cycling. The first plot shows the best algorithm using a frequency-by-frequency comparison; the second plot used the peak comparison algorithm with smoothed data. In this case there is a significant improvement in separation between the populations.

H. MC&A Data Analysis and System Evaluation Technology

Current procedures within DOE for evaluating the effectiveness of proposed and existing safeguards systems

are resource intensive. Technology developed in this task will reduce data requirements and personnel resources used in these analyses. In addition, work in this task will apply statistics, mathematics, operations research, and decision analysis techniques in developing computerized tools that support more efficient use of MC&A information at DOE facilities. These software products will aid DOE field offices and contractors in the design and evaluation of modernized MC&A systems and in the analysis of MC&A data to detect and resolve anomalies.

1. Fuzzy Logic in Nuclear Safeguards: A Perspective (A. Zardecki, NIS-7). There are two known approaches to deal with uncertainty and imprecision. The first approach, a traditional one, is based on the theory of probability. In fact, decision making under uncertainty is regarded by some authors as synonymous to statistics. The second approach, the theory of fuzzy sets, begun in the mid-sixties, relies on possibility theory. Just as probability assigns a probability measure to a set or event A , possibility

assigns a possibility measure to A . For example, if A' is the contrary event, then for probability measure P , we have

$$P(A) + P(A') = 1,$$

while for possibility measure P^2

$$\max[\Pi(A), \Pi(A')] = 1,$$

which can be interpreted as the fact that of two contradictory events, one at least is completely possible. Consistent with the notion of possibility, one can also say that to realize a union of two events, it is sufficient to realize the less costly of the two.

In essence, to paraphrase Zadeh,³⁶ the theory of fuzzy sets is aimed at the development of a body of concepts and techniques for dealing with sources of uncertainty and imprecision that are non-statistical in nature. It answers a

Fig. 18a

Fig. 18b

Figs. 18a&b. These two figures show the results of different comparison algorithms applied to the same data. In the first case, thermal cycling significantly reduced the ability to distinguish between cases where tampering occurred from cases where tampering did not occur. With a different algorithm (Fig. 18b), thermal cycling only minimally affects the ability to distinguish between tampering and not tampering.

paradox first propounded by Zeno, an ancient Greek philosopher: if you remove the grains from a pile of sand one at a time, at what point does it cease to be a pile? The fuzzy answer is that the pile of sand is reduced as smoothly as the individual grains are taken away from it. Probability measures the likelihood of something happening. Fuzziness measures the degree to which it is happening. Knowing how likely it is to rain tomorrow is not the same as knowing how heavily it is raining today.

With the advent of fast computers, several new techniques are being applied in nuclear safeguards. For example, a methodology for monitoring nuclear reactor systems has been formulated in terms of a combination of neural networks and fuzzy logic by Ikononopoulos, et. al.³⁷ Over the last few years, we have applied fuzzy logic to system performance evaluation, risk assessment, resource allocation, and—currently—to anomaly detection.

System Performance Evaluation. The characterization—with respect to assurance—of the performance of containment and surveillance devices as well as vulnerability assessment, sabotage countermeasures, and risk analysis can be achieved by a figure of merit M , which is regarded as a product of three factors: non-diversion possibility, reliability, and assurance. In the fuzzy logic approach, linguistic attributes such as low, medium, and high replace the subjective characterization parameters of individual components of the system. The overall figure of merit is then obtained by combining the figures of merit of individual components.³⁸

Fuzzy Risk Assessment. The fuzzy risk assessment applies to a system composed of units that can describe the system hierarchically. One merely climbs the tree of decomposition, computing the risk of each interior node from the risk values of its descendants, until one arrives at the root node.³⁹

At the lowest level, the terminal nodes have three attributes associated with them. They are probability of failure, severity of loss, and confidence factor. The fuzzy product of these attributes, defined as an extension of the product of real numbers, results in a component risk indicator of the node. This is analogous to the figure of merit used in the fuzzy performance evaluation. The component risk indicators of the descendants of each parent node are then weighted by the weight factors to produce the parent's node risk indicator. The weight factor, therefore, adds or subtracts weight from the risk indicators as they are merged into higher level indicators. The non-terminal nodes, which rely on their descendants, do not require the three attributes of terminal nodes.

As an illustration, we show in Fig. 19 the results of the risk assessment for a facility fragment dealing with the alarm system. For the sake of simplicity, we set the confidence factor equal to unity for all the nodes of the alarm data structure. With the input listed in Table III, we arrive

at the overall risk estimate as medium to high, which translates into a numeric risk indicator of 0.59. The critical path is indicated in Fig. 19 by shaded nodes.

This risk assessment methodology has been applied to the Rocky Flats reconfiguration and to the security plan of a technical area at Los Alamos National Laboratory.

Fuzzy Resource Allocation. Providing adequate protection for nuclear materials is a complex undertaking that draws on expertise from many technical disciplines. Safeguards systems have steadily improved along with the public's desire to reduce the risk it perceives from safeguards operations. Modern systems studies attempt to describe safeguards in terms of three functions: authorization, enforcement, and verification.⁴⁰ The risk analysis of a complex system is an essential element of the integrated system design. A related problem is to assign limited resources to safeguards elements by minimizing the overall risk. Customarily, this has been achieved by maximizing the probability of detection against a range of scenarios—the object of the optimum resource allocation.

We have proposed a novel approach, based on the notion of fuzzy sets, to the risk analysis and to the resource allocation problem.⁴¹ As in the investigation of system performance, the key postulate is to replace the numeric attributes by the linguistic ones. This suggests that much of the uncertainty intrinsic in the system analysis is rooted in the fuzziness of the information that is resident in the database and, more particularly, in the fuzziness of underlying probabilities.

Automated Anomaly Detection. The problem of nuclear materials control has traditionally been formulated in terms of classical statistical methods or by using specialized techniques, such as Kalman filtering. With the advent of fast computers, several new techniques are being applied to nuclear safeguards. The new tools involve neural networks and fuzzy control. As compared to neural networks, the fuzzy controllers can operate in real time; their learning process does not require many iterations to converge. For this reason fuzzy controllers are potentially useful in time series forecasting, where we seek to detect and identify trends in real time. The algorithm we advance is based on forming a difference between the observed and forecasted values, as shown in the simulated data of Fig. 20.

A small signal centered around time $t = 100$ is not visible on the value plot, but appears clearly on the plot of the forecast error. Analysis indicates that forecasting based on fuzzy control is a technique that, because of its simplicity and power, should be considered as a data evaluation tool in advanced safeguards applications.

2. Resource Allocation Optimization Program for Safeguards (RAOPS) Algorithm and Software Development (A. Zardecki, NIS-7). RAOPS⁴² provides an

Fig. 19. Decomposition of the alarm system into component parts. Shaded nodes indicate the critical path.

example of the resource allocation problem in which the overall detection probability is the single objective function. Other examples of this type of single-criterion optimization problem include the resource allocation problem with fuzzy detection probabilities⁴¹ and the defense in depth problem, solved by stochastic optimization.⁴³ When we want to maximize the detection probability and minimize the detection time, we face the multi-objective optimization problem.⁴⁴

We introduce the expected detection time by following the procedure described by Avenhaus⁴⁵ in the context of the optimum number of inventory periods. If the time needed to reach the k th detection element is T_k , then the expected detection time T is given as

$$T = \frac{\prod_{k=1}^n T_k P_k \prod_{i=1}^{k-1} (1 - P_i)}{1 - \prod_{k=1}^n (1 - P_k)}.$$

Here, P_i is the detection probability, regarded as the optimal detection probability determined through the final-state optimization.

A supplementary benefit of the forward dynamic programming solution is that it spawns trajectories reaching different terminal states. To each trajectory, defining the total return with a given amount of remaining resources, a terminal constraint can be applied. If other criteria—such as the expected detection time—are considered, the trajectory satisfying these supplementary criteria can be selected.

As an illustration of our considerations, we use a simple serial arrangement of four activities, with the assumed total budget of 10 units. The solution to the backward recursion scheme is displayed in Fig. 21, in which the detection probability is shown as a function of the available budget. It is evident that, beyond a certain budget, the detection probability does not increase fast enough to justify an additional investment.

When the expected detection time is evaluated, the solution—obtained by the forward recursion method—is shown as a function of the remaining resources. This solution is shown in Fig. 22. In Fig. 23, we show the expected detection time as a function of available budget.

As should be intuitively clear, the detection probability decreases as the remaining funds accumulate. The expected detection time displays a maximum for the remaining funds of seven; it is reasonably small when four units of the initial budget remain. This implies that, with the total budget of 10 units, the allocation of 6 units leads to the highest detection probability and a reasonable value of the expected detection time.

The implementation of the multicriteria resource allocation problem, with the overall detection probability and expected detection time viewed as the joint return function, leads us to the following conclusion. Whereas the backward recursion is the natural tool for solving the standard resource allocation problem, the forward recursion is better adapted to the multi-objective allocation.

TABLE III. Input Data to the Alarms Fragment of Facility Risk Assessment

Node ID	Description	Likelihood of Loss	Severity of Loss	Weight
Ala	Alarms			
Int	Security Alarms			Medium to High
Tam	Tamper	Fairly Low	High	Low
BMS	Door Contact Alarm	About Two	Medium	Medium
Mot	Motion	Low	Very High	High
PID	Exterior Perimeter Alarms			Medium
Sen	Sensor - Type 1	Medium	Medium	Medium
Sen	Sensor - Type 2	Medium	Medium	Medium
Ass	Alarm Assessment	Low	Low	Medium

Fig. 20. The plot of the forecast error indicates the existence of an anomaly in the time series.

RAOPS can be used as a design tool preventing costly, and perhaps minimally effective, modifications to the facility design, once the facility is in operation.

I. Computer File Transfer (W. J. Huntman, NIS-12)

During October 1993 the original goals for this activity were overtaken by advances in technology and changes in the DOE contractor community. This task was originally intended to conduct a technical evaluation of a special unit developed by EG&G for controlled transfer of files between a secure and an open network. Other activities by the National Security Agency (NSA) were addressing the same problem and were announced in late summer 1993. The NSA unit and declining budgets at the DOE con-

Fig. 21. Detection probability as a function of available budget.

tractor facilities in late 1993 resulted in a review of the NSA unit and a decision by DOE/OSS that DOE should not spend any resources on the EG&G unit. A number of other activities related to multi-level networks and the transfer of data between secure and open networks were substituted for the original task. The activities included the following:

1. A Los Alamos staff member participated as a consultant during the development of transition plans for developing a multilevel network for DOE/NN-50. The activities included several meetings to collect information on current and planned DOE/NN-50 computing resources.
2. A number of meetings were held with Martin Marietta personnel to discuss the details of migrating from the present separate secure and open networks to a single multilevel network for NN-50.
3. A team of LLNL, Martin Marietta, and Los Alamos personnel interviewed data owners and system designers of DOE/OSS information systems and databases to collect information on the development efforts and plans for these systems. The data were used as part of a computer security analysis of these systems and databases. A draft report documenting the analysis was completed in December 1994. The final report will be issued in January 1995 after review by DOE/OSS.
4. We began to define a common set of requirements for DOE classified and unclassified information. This work has been merged into the working group chartered to write new policies for the protection of classified information in the US Government. A presentation on the preliminary results of this work was made at the November 1994 Computer Security Advisory Group conference in Oak Ridge, TN.
5. A Los Alamos staff member reviewed an early draft of the international information technology criteria, called the Common Criteria (CC). This review was requested by NIST and was intended to validate the approach taken by the CC development committee. The review was followed by a request from NIST in December 1994 to review the entire CC in early 1995.

II. CONCEPT AND DEMONSTRATIONAL DEVELOPMENT

A. Measurement Control and Calibration

The goals of this task are to develop cost-effective calibration standards and measurement control concepts based on an understanding of NDA measurement physics

Fig. 22. Detection probability as a function of the remaining funds.

and to support DOE facilities in demonstrating and implementing these concepts. The task also supports our participation in the preparation and review of American National Standards Institute (ANSI) and American Society for Testing and Materials (ASTM) consensus standards.

1. New Analysis Technique for K-Edge Densitometry Spectra (S.-T. Hsue and M. L. Collins, NIS-5). Existing algorithms for the analysis of K-edge densitometry spectra have allowed the determination of the concentration of only one or two heavy elements in a liquid solution. The single-element analysis technique uses data from two 6-keV-wide fitting windows: one below and the other above the K-edge for that element.⁴⁶ The dual-element technique applies only to elements that differ by two in proton number (for example, thorium and uranium, or uranium and plutonium).⁴⁷ The dual-element method uses data from three fitting windows: a 6-keV-wide region below the lower K-edge, a 2-keV-wide region located between the two K-edges, and a 6-keV-wide region above the upper K-edge. Because the 2-keV-wide fitting region is used for both elements in the dual case, fewer data points are needed for each element than in the single-element technique. The availability of less data leads to an increased uncertainty in the results, which is one limitation of the dual-element method.

If there is only one element in a liquid solution, its concentration can be measured with excellent precision using the single-element analysis method. However, liquid samples may contain multiple elements. When the single-element technique is applied to mixed solutions, the contaminants cause a bias in the measured concentration of the major element. The algorithm for dual element analysis compensates for the bias that occurs, for example, in the concentration of uranium caused by the presence of thorium, and vice versa. However, the dual-element technique applies to solutions that contain only two heavy elements. Presence of additional elements will bias both measured concentrations, another limitation of the dual-element technique.

The following mixtures are common in multi-element solutions: (1) uranium as major element, with thorium as minor element; (2) uranium as major element, with plutonium, neptunium, and americium as minor elements; and (3) plutonium as major element, with uranium, neptunium, and americium as minor elements. For many solutions, although the concentration values are not known, the ratio of one element's concentration to another is known from another measurement. For some solutions, more than one ratio is known. Ratios that are commonly known include thorium/uranium, plutonium/uranium, neptunium/plutonium, and americium/plutonium. These ratios, and their associated uncertainties, provide useful information about the contents of a mixed solution. This information, if available, should be used in the analysis routine as a constraint on the concentration values it calculates.

The *known ratio analysis technique* is based on the logic that if one ratio is known, it should be possible to calculate the concentrations of both elements in the ratio by measuring the concentration of the major element. Suppose that a solution contains only uranium and thorium, and it is known that $\text{Th/U} = 0.05$. If the uranium concentration is measured to be 100 g/L, we know the Th concentration should be 5 g/l. Similarly, if two ratios are known, and both ratios have one element in common, we should be able to determine the concentrations of all three elements by measuring the concentration of the dominant element. For example, suppose that uranium is the major element in a solution, with minor elements plutonium and americium. If the ratios Pu/U and Am/Pu are known, and the concentration of U can be determined, the concentrations of plutonium and americium can be calculated directly. For the known ratio technique to succeed, the major element concentration must be determined precisely; the minor element concentrations are inferred from this value. Unfortunately, the presence of minor elements creates a bias in the measured concentration of the major element. The minor element concentrations, therefore, would contain a similar bias.

Fig. 23. Expected detection time as a function of the remaining funds.

If we knew the concentrations of all the minor elements, and their mass attenuation coefficients, we could mathematically "de-attenuate" their effects from the original spectrum. De-attenuation would create an altered spectrum, representing the spectrum we would expect to observe if all the minor elements had been absent from the solution. With the effects of minor elements removed, the major element concentration could be determined via the *single element* analysis technique. De-attenuation removes the bias that results in the major element concentration due to the contaminants. However, we are given the ratios of one concentration to another, not the minor element concentrations themselves. On the one hand, we can measure the concentration of the major element, but the value obtained will be biased. On the other hand, we can remove this bias, but to do so we need the minor element concentrations. The solution to this problem is to use an iterative scheme.

Before the iterative method is begun, the original solution spectrum must be stored for future access. See Fig. 24 for an example of original spectral data. In the first iteration, the *original* spectrum is analyzed (using the single-

element analysis technique) to determine the concentration of the key element. We assume this value is biased and proceed to calculate the minor element concentrations using the known ratios. We assume the minor element concentrations are biased, and proceed to de-attenuate their effects from the *original* spectrum. This creates an alternative spectrum, which will contain a decreased bias in the key element caused by the other elements. In the iterations that follow, the *alternative* spectrum is analyzed (using the single-element analysis technique) to determine the concentration of the key element. Minor element concentrations are calculated, and the *original* spectrum is de-attenuated, creating a new alternative spectrum. Figure 25 illustrates an example of de-attenuated spectral data. Six iterations, in most cases, provide convergence on a final result. This method requires that the major element in the solution be chosen as the key element. Choice of a minor element as the key element can lead to divergent results, suggesting that a different key element should be used.

2. Deming Curve Fitting Program (R. A. Cole, P. M. Rinard, and T. Marks, NIS-5). The Deming Curve

Figure 24. Densitometry spectrum of a mixed thorium and uranium solution. Transmission T represents the ratio of net observed counts to net reference counts, and E represents the energy in keV, corresponding to each channel. Element concentrations are calculated by performing linear fitting on data in $\ln(\ln(1/T))$ vs $\ln(E)$ space. Note thorium K-edge at left, and uranium K-edge at right. Plotted points represent data obtained in the laboratory; a solid line indicates data obtained by means of simulation. When the single element analysis technique is used to determine the concentration of uranium, the presence of thorium creates a bias in the measured value.

Figure 25. Densitometry spectrum of a mixed thorium and uranium solution, after six iterations of the known ratio technique. In this sample, the Th/U ratio was known to be 0.0566. Plotted points represent data obtained in the laboratory; the solid line indicates data obtained by simulation. Both data sets in this plot were "de-attenuated," so that the attenuation effects of the thorium have been removed mathematically. Note disappearance of thorium edge at left; the uranium edge remains at right. The single element analysis technique can now be applied to these spectra to determine the uranium concentration, with negligible bias from the thorium.

Fitting program written by P.M. Rinard based on the algorithm proposed by W. E. Deming⁴⁸ has been widely used in the safeguards community.⁴⁹ This program fits equations that are nonlinear in the parameters and data sets that have uncertainties in both the independent and the dependent variables. In addition, it provides a pre-programmed set of equations for fitting the data.

This project has taken the earlier Deming program and adapted it into the Windows* environment. Thanks to a graphical user interface (GUI), the new program is easier to use than the earlier DOS version. Students in a recent offering of the "Nondestructive Assay Techniques for Safeguards Practitioners" course were enthusiastic about being able to use Deming Curve fitting in the Windows environment. Figure 26 shows the typical appearance of the computer display for the program.

In addition to ease of use, the new implementation has addressed the desire to integrate the Deming Curve Fitting capabilities easily into other NDA applications. Although the focus was to run the code on PC-compatible computers, recent developments in the computing world

have made it possible to use the program on other desktop computers and workstations.

3. ASTM Standards Development.

a. **ASTM Subcommittee C26-10 NDA Consensus Standards (J. K. Sprinkle Jr., NIS-5; Ken Coop, NIS-6).** We are continuing to support the transfer of Los Alamos developed technology to others by participating in the ASTM Subcommittee C26.10. Our goal is to promote standardization of these measurement techniques between users and facilities to provide results of equal quality to everybody who uses the technique. Excellent progress was made on several standards: neutron-based measurements of nuclear waste containers, using the californium shuffler and differential die-away techniques (DDTs), several standards dealing with segmented gamma-ray scanning, and a guide for the measurement of process holdup. The californium shuffler test method is expected to be ready for balloting early next year.

b. **ASTM Subcommittee C26-12 Consensus Standards for Material Control (P. E. Fehlau, NIS-6).** This year, the subcommittee concentrated on completing two standards for adjusting metal detectors that are used to

*Windows is a trademark of Microsoft Corp.

Fig. 26. Computer display for Deming program.

detect weapons and metallic radiation-shielding materials. The two have now passed the balloting procedure, they have been given the numbers shown below, and they will appear in Volume 12.01 of the ASTM book of standards printed in September 1994.

ASTM C1270-94, "Practice for Detection Sensitivity Mapping of In-Plant Walk-Through Metal Detectors."

ASTM C1269-94, "Practice for Adjusting the Operational Sensitivity Setting of In-Plant Walk-Through Metal Detectors."

During the year, the subcommittee also worked on draft standards for testing the performance of metal detectors and for designing entry-control facilities.

B. NDA Engineering Development

The objectives of this task are to develop newly engineered detector configurations, electronics, software, and mechanical systems for NDA instruments to meet the demands for automation, remote location, unattended operation, and compactness required for improved MC&A. The task also supports development of new NDA instruments for integrated MC&A systems needed by both existing and reconfigured DOE processing and storage facilities.

1. WIN_TGS Software (R. Estep and J. Cavender, NIS-6). We continued development of the WIN_TGS data acquisition and scan control software for TGS and SGS systems. WIN_TGS is an exceptionally user-friendly C++ Microsoft Windows 3.1 application that communicates and shares data with related applications using a modular "black-box" approach. WIN_TGS was described in a paper⁵⁰ presented at the 1994 Annual INMM meeting in Naples, Florida. The program is currently in use at Los

Alamos as a beta test version. Over the next year, it will be revised and upgraded and will undergo quality assurance auditing so that it can be distributed to several DOE sites.

While the main use for WIN_TGS will be in TGS/SGS systems, it has much broader potential application for generic scan control and data acquisition. In general, WIN_TGS controls an arbitrary number of stepper motors while collecting data from an arbitrary number of MCAs. To realize this generic capability, we have developed and implemented the "TPR" scan control and data acquisition protocol language, which allows users to write their own scanning and data acquisition protocols. In addition to the basic, easy-to-use set of motor control and MCA commands, the TPR language supports floating point variables, math functions (=, +, -, /, *, SQRT=, EXP=, COS=, etc.), user input and output, and program flow logic (IF-ELSE branching, GOTOs, and looping). WIN_TGS system parameters are assessed through global system variables, so that scanner settings entered in WIN_TGS dialog boxes can be used in a user-defined scan protocol. Alternatively, users can design and build their own custom dialog boxes for parameter input.

Real-time hardware programming is difficult in Windows 3.1 because of its non-preemptive multitasking, which gives the built-in Window's timer functions a very low priority. Because of this difficulty, we used an Omega 9513 timer/counter card as a basis for our own interrupt-driven timer function library. This method is portable across all PC platforms (for example, it should port to OS/2 or Windows NT) and provides timing functions that are accurate to within fractions of a millisecond without placing undue burden on the already overworked PC system clock interrupt.

Other improvements to WIN_TGS made during FY 1994 include

- a smart I*2 binary file format that significantly reduces the size of TGS raw data files,
- upgrade of the motor control library to use Compumotor 4000 and AX/SX controllers,
- improved region-of-interest editing,
- an optional generic (non-TGS) user interface,
- support for different sample types,
- support for arbitrary scan resolutions, and
- simulated two-MCA operation with only one MCA.

2. TGS Preliminary Design Study (R. J. Estep, NIS-6). We published a report⁵¹ describing design studies done during the previous two years on our original experimental prototype TGS scanner. This report focuses mainly on the improved accuracy obtained using our novel, diamond-shaped collimator along with continuous-motion scanning, as described in previous annual reports. We consider this study to be preliminary because a more detailed design study using our newer, well-engineered prototype scanner is planned.

C. Instruments and Measurement Systems for Nuclear Facilities

The goals of this ongoing task are to develop and demonstrate improved NDA measurement concepts in nuclear material processing and storage facilities. In support of Complex reconfiguration, we provide improved measurement capability for safeguarding against insider threats, in-line T&E of new measurement technology, and integrated measurement systems for improved near-real-time accountability. (Portions of some of these activities are supported by facility funding.)

During FY 1994, a number of important developments took place in the application of OSS technology to facility measurement problems. These are described in detail elsewhere in this report and are summarized here. We completed a test and evaluation of the Tomographic Gamma-Ray Scanner Prototype using actual TRU waste drums from the Los Alamos waste storage and burial site (see Part I, Sec. I.C.3.). The Weapons Dismantlement NDA System for the Los Alamos Plutonium Facility is currently being assembled and tested in the laboratory (see Part I, Sec. I.C. 6.). A new Windows-based version of the FRAM Plutonium Isotopic Analysis System has been developed for use in this Weapons Dismantlement NDA System (see Part III.D. 6. "FRAM Plutonium Isotopic Analysis System Development"). Development of the Multi-Position Add-a-Source Waste Drum Assay system has been completed and is undergoing evaluation in the Los Alamos Plutonium Facility (see Part I, Sec. I.E.1). The Hybrid (K-Edge/XRF) solution assay instrument for the Los Alamos

Plutonium Facility has been designed and is being fabricated. In addition, a new analysis technique for the densitometry portion of the system has been developed (see Part I, Sec. II.A 1). We also developed an integrated SGS/Isotopics NDA system for Savannah River (see Part III, Sec. I.D.)

Other facility activities included support for the Portsmouth Solution Enrichment Systems, the Livermore and Los Alamos Californium Shufflers (see Part I, Sec. III.A.8.), and the Savannah River Billet Shuffler. In addition, the test and evaluation of the Waste Crate Assay System delivered to the Los Alamos Plutonium Facility has been documented and reported at the 1994 Annual INMM Meeting.

D. Holdup Determination and Analysis for Nuclear Facilities

The goal of this task is to develop and demonstrate new NDA concepts for measuring holdup or monitoring in-process inventory in support of facility inventory difference determination, material roll up determination, or facility reconfiguration or decommissioning. Quantifying holdup continues to pose problems because of complex geometries, difficult access, large and variable backgrounds, and lack of appropriate standards for calibration. This task includes developing dedicated instruments for selected process equipment and portable instruments for ad hoc measurements, with T&E at operating facilities. (Portions of many of these activities are supported by facility funding.)

1. Continuous Neutron Monitoring (CNM) of an Aqueous Plutonium Recovery Process (P. A. Russo, NIS-5; D. W. Gray, NMT-3). The CNM, based on compact, reliable technologies using ³He gas proportional counters, was developed and field-tested for real-time determination of the quantitative conversion of solid actinide oxides to fluorides in the metal preparation line of the LAPF.⁵² Recently, the metal preparation line has been dismantled and the CNM moved to a new location to demonstrate the feasibility of monitoring actinide conversions in solution. This new location is an automated process for the recovery of actinide alpha-particle emitters (plutonium, americium) from neutron sources (such as PuBe and AmLi). The high neutron yield for selected low-Z targets occurs when the Q value for the (alpha, n) reaction is favorable and the target nuclides are nearest neighbors of the alpha-particle emitters. Thus, dissolution of these neutron sources results in a dramatic decrease in the neutron yield. Monitoring the process up to and through dissolution supports minimization, as well as real-time evaluation, of radiation doses to operators and contributes to optimum efficiency of the operations. Because this front end of the new test process has been automated by robotics, it is well matched to the CNM concept of continuous, automated readout.

Figure 27 shows the real-time readouts of neutron count-rate obtained in continuous 100-s count periods during the second run of the new process for recovery of a small PuBe source. The two CNM detectors are positioned side-by-side in the polyethylene shield on the opposite side of a wall behind the recovery glove box. The polyethylene-moderated ^3He tubes, 1 and 2, are located approximately 48 and 60 cm, respectively, from the dissolution vessel. The first 60 min. correspond to introduction of the source into the process line followed by the automated mechanical handling and machining operations that release the source material from the encapsulation. Dissolution occurs during the next 20 min. Equal (room-background) count rates for the two identical detectors indicate completion of dissolution and demonstrate the process monitoring concept that uses the ratio R of count rates to follow the process to (and predict the time of) completion at $R = 1$.

2. Integrated Holdup Measurement System (IHMS) (P. A. Russo, J. K. Sprinkle, Jr., J. K. Halbig, S. F. Klosterbuer and S. E. Smith, NIS-5). The IHMS addresses the need at the Oak Ridge Y-12 plant and elsewhere for bimonthly plantwide determination of the quantities of SNM held up in process equipment. The integrated system is a generic package that consists of

1. complete, self-contained hardware for portable gamma-ray spectroscopy that can be easily carried and simultaneously operated by a single user;
2. firmware for automation of setup, operation and quality assurance of gamma-ray spectral data;
3. compact, collimated, shielded gamma-ray detectors for spectroscopy;

4. programmable bar-code-reader/data-logger technology for rapid, automated measurement capability free of transcription errors;
5. automation of assay algorithms and formalism that generalize measurement geometries to simplify the calibration and measurement process; and
6. software to automate routine operation for use of the IHMS by minimally trained personnel who are unfamiliar with gamma-ray spectroscopy.

The integrated system also relies on a detailed, facility-specific database that documents the detection geometry for each individual measurement, the process equipment materials and equipment dimensions at each measurement location, and the extended process equipment dimensions.

Items 1 and 2 consist of the Los Alamos prototype Miniature, Modular MultiChannel Analyzer (M³CA), described in Part 1.III.A.3. As of this year, two of these units reside at Y-12 for the field evaluation of the integrated holdup measurement system. Item 3 for the field evaluation consists of the compact NaI(Tl) detector, developed originally at Los Alamos and now available commercially. Item 4 is commercial equipment that has been proven reliable in many years of application at Y-12. Item 5 is based on the generalized-geometry holdup algorithms developed at Los Alamos. Automation under items 5 and 6 consists of the Holdup Measurement System II (HMSII) software developed by Y-12 personnel in cooperation with Los Alamos. The facility-specific database continues to be built up at Y-12.

Several hardware and firmware upgrades for the M³CA have been implemented during the past year. The

Fig. 27. Neutron count rate vs time obtained in continuous 100-s count intervals for CNM detectors 1 and 2 during a PuBe recovery operation through the dissolution step.

HMSII software, originally written and tested for use with the Davidson portable multichannel analyzer (PMCA), is now operational with the M³CA. The first testing of the IHMS with the M³CA and the corresponding version of the HMSII software took place at Los Alamos during the 1994 DOE training seminar entitled "Nondestructive Assay of SNM Holdup." Individual students used automated IHMSs to perform the complete set of holdup measurements and analyze and document the results in just a fraction of an hour, compared to an entire day of effort required with the conventional portable technology.

During the next calendar year, the IHMS will be tested in two uranium measurement applications at Y-12, one performed on rooftops and the other in basement ductwork. The latter measurements will be followed by a cleanout and analysis of recovered material, a remeasurement with the IHMS of the equipment and a comparison of the IHMS results with the cleanout values. Efforts are also underway to implement the IHMS (with the Davidson PMCA initially) for routine measurements of plutonium holdup at the LAPF.

3. Glove Box Holdup Measurement System for the Experimental Cascade Dissolvers (J. K. Sprinkle Jr., P. A. Russo, and R. Siebelist, NIS-5). The monthly inventory cleanout requirement for this plutonium scrap recovery process reduces the productivity and increases the radiation exposure of the operators. We tested measurement procedures that will reduce the inventory frequency when they are implemented by the facility operator and accepted by the nuclear materials oversight group. The goal is to reduce the need to tear down and clean out equipment from a monthly to a semiannual practice.

Measurements of these dissolver tanks are difficult because up to 5 kg of solid feed can be distributed nonuniformly in each of three 5-L columns. The initial gamma-ray measurements were a partial success. We began automating the measurement procedure, initializing the HMSII database,⁵³ and then waited for resolution of mixed-waste disposal issues. The field test of the automated procedure was never completed. By the time the disposal issues were resolved, the facility priorities for processing plutonium shifted away from the dissolver we were using as a test bed.

4. Verification of Quantitative Determinations of HEU Holdup in Process Equipment for Decontamination and Decommissioning (D&D) (P. A. Russo and R. Siebelist, NIS-5). In the fall of 1993, the ²³⁵U holdup in more than 100 hoods and glove boxes in a Los Alamos facility designated for D&D was assayed nondestructively by gamma-ray spectroscopy and the generalized-geometry (GG) approach using compact sodium iodide (NaI) detectors²⁷ and the generalized-geometry holdup (GGH) program.⁵⁴ Seven of ten hoods that contained furnaces had unusually high ²³⁵U assays. In the fall of 1994, the excess

residues from ²³⁵U processing were removed from these ten hoods and assayed by neutron coincidence counting (NCC) in the AWCC. The residual ²³⁵U holdup in the hoods was subsequently assayed with the GG approach using the compact NaI detector and the GGH program, as before. The main purpose of this latter activity was to obtain final (after residue cleanout) closeout values for ²³⁵U in the residues and hoods for recycle and disposal purposes, respectively. A secondary purpose was to compare the ²³⁵U results for the residues with the difference between the Fall 1993 and Fall 1994 holdup results for the glove boxes as a verification of the holdup measurement capability.

The initial residue was cleaned out by manual sweeping of solids from accessible surfaces in the hoods, with efforts to segregate the residues by hood origin. The swept residues were transferred to polyethylene screw-cap jars, and the ²³⁵U was assayed nondestructively by the AWCC/NCC. Because significant additional quantities of solids were observed in difficult-to-reach locations on the floors within the hoods, a vacuum cleaner was used in a second effort at solids removal. The contents of the vacuum bags were transferred to polyethylene screw-cap jars and were also assayed for ²³⁵U content by the AWCC/NCC. Because adjacent hoods were open to one another, "segregated" swept and vacuumed residues inevitably came from multiple hoods. The relatively small quantities of ²³⁵U that remained within the vacuum-cleaner bags were assayed by the gamma-ray GG approach. Finally, the same gamma-ray GG assay method and procedures used originally in 1993 were repeated to obtain the residual ²³⁵U mass in the hoods (with the exception of, in the interest of time, Hoods 41-43) after residue removal.

Columns 2 and 3 of Table IV give the ORIGINAL (1993) and PRESENT (after residue removal) gamma-ray GG assays of ²³⁵U mass for each hood as well as the total gamma-ray GG assay of ²³⁵U mass for each group of adjacent (consecutively numbered) hoods. Column 4 is the difference in ²³⁵U mass between the present and original gamma-ray GG assay for each group of adjacent hoods. This difference should be comparable to the ²³⁵U mass in the residue that was removed. It should be noted that the adjacent hoods are not separated by any physical barriers.

Columns 5 and 6 of Table IV give the AWCC/NCC assays for ²³⁵U mass in the swept and vacuumed residues for the individual hoods (to the limited extent that segregation by hood was possible) and the totals for adjacent hoods. Column 7 is the ²³⁵U mass remaining in the vacuum bags, measured by the gamma-ray GG assay for all vacuum bags combined for adjacent hoods. Column 8 is the total ²³⁵U mass, measured in all residues (combined for adjacent hoods). Column 9 of Table IV is the RATIO of the ²³⁵U mass determined by the ratio of the GG holdup assay (DIFFERENCE) to that of the measured residues removed (TOTAL RESIDUE). Agreement between DIFFERENCE and TOTAL RESIDUE (RATIO = 1) is a verification of the gamma-ray GG assay approach.

TABLE IV. Holdup and Residue Assays of ^{235}U in the Furnace Hoods.

HOOD ID	$\text{g } ^{235}\text{U}, [\sigma \text{ g } ^{235}\text{U}]$			$\text{g } ^{235}\text{U}, [\sigma \text{ g } ^{235}\text{U}]$				RATIO (DIFF. / TOT. RESIDUE) [σ RATIO]
	ORIGINAL (γ , Nov. '93)	PRESENT (γ , Oct. '94)	DIFFERENCE (ORIG. - PRES.)	SWEPT RESIDUE (n , Oct. '94)	VACUUMED RESIDUE (n , Oct. '94)	VACUUM BAGS (γ , Oct. '94)	TOTAL RESIDUE	
H2	283 [4]	206 [3]		25 [6]	83** [8]			
H3	132 [3]	62 [2]		140 [3]	91 [5]			
H4	254 [3]	134 [2]		152 [20]	34 [3]			
H5	606 [7]	362 [5]		82 [12]	208 [3]			
TOTAL	1275 [10]	764 [7]	511 [12]	399 [1]	388 [5]		645 [27]	0.79 [0.05]
H22	136 [2]	127 [2]		75 [6]	112 [5]			
H23	126 [2]	82 [2]		41 [7]	65 [7]			
H24	142 [4]	116 [3]		109 [7]	34 [7]			
TOTAL	404 [5]	325 [4]	79 [7]	225 [1]	211 [4]	26 [2]	463 [16]	0.17 [0.02]
H41	12 [1]	NOT MEASURED		7 [4]	3 [3]			
H42	14 [1]			0 [1]	1 [2]			
H43	15 [1]			7 [1]	3 [1]			
TOTAL	41 [2]	18* [6]	NA	14 [1]	7 [3]	2 [1]	23 [6]	NA

* $\text{g } ^{235}\text{U}$ (ORIGINAL) - $\text{g } ^{235}\text{U}$ (TOTAL RESIDUE)

** Vacuumed residues were combined for Hoods 2 and 3.

In the course of this analysis, it was discovered that, in the original holdup measurements of Hoods 22-25, only the upper halves of the hoods were measured because the measurement team was not aware that the process equipment behind the closed hood-cabinet doors extended vertically down to the floor, rather than ending at the waist-high furnace shelf. Because most of the swept and vacuumed residues were removed from the floor surface, the removal of residue was, largely, not reflected in the DIFFERENCE results for Hoods 22-25 because measurements below the furnace shelf height were not performed. Thus the RATIO values for Hoods 22-25 are anomalously low. The gamma-ray GG measurements of Hoods 2-5 were performed over the full heights of the hoods, and thus the values of RATIO for Hoods 2-5 are more reasonable. The value of 0.79 (~20% below 1) for RATIO indicates that the original gamma-ray GG results may have been biased low by ~20% as a result of significant self-attenuation of the 186-keV assay gamma rays by the original large ^{235}U mass in Hoods 1-5. Although RATIO cannot be evaluated for Hoods 41-43 because the holdup in these hoods was not remeasured after residue removal, the TOTAL RESIDUE quantity, 23 g of ^{235}U , is about half of the ORIGINAL holdup (41 g of ^{235}U) measured for these three hoods, similar to the analogous relationship (645 g compared to 1275 g of ^{235}U) for Hoods 2-5. TOTAL RESIDUE for Hoods 22-24 (463 g of ^{235}U) is approximately equal to the PRESENT ^{235}U mass (325 g of ^{235}U), consistent with the analogous quantities for Hoods 2-5 (645 vs 764 g of ^{235}U ,

respectively) indicating that the gamma-ray GG assay result for the PRESENT ^{235}U mass in Hoods 22-24 is reasonable.

E. Confirmatory and Inventory Verification Measurement Systems

The goal of this task is to develop confirmatory and inventory verification measurement concepts for shipped or stored nuclear materials and demonstrate them in processing and storage facilities. The task includes problems associated with shipment and receipt of nuclear materials, the inventory verification of stored nuclear materials, determination of the special nuclear material content or configuration in different types of nuclear materials or nuclear devices, and with the verification of weapons or dismantled weapons components. (Portions of many of these activities are supported by facility funding.)

1. HEU Shipper Receiver Confirmatory System (SRCS) (J. K. Sprinkle Jr., and R. Siebelist, NIS-5; C. Garcia, J. Martinez, and L. Trujillo, NIS-6). DOE Orders require confirmation measurements for shipments between nuclear facilities when accountability measurements are not feasible. The issue of concern is whether all of the SNM that left facility A arrived at facility B. DOE Orders also use the term confirmation in the context of periodic inventories, when the issue is that verification measurements are not feasible on items that lack TIDs or valid

measurement codes. We used our experience⁵⁵ with the SRCS measurements of HEU and low-enriched uranium (LEU) for shipments of SNM between facilities as a platform to develop inventory confirmation measurements. The presence of HEU is indicated by a strong emission at 186 keV, a weak emission at 1001 keV, and an emission at 2614 keV. The presence of LEU is indicated by emissions at 186 and 1001 keV and no emission at 2614 keV. Uranium of any enrichment does not exhibit an emission at 350-400 keV that indicates plutonium, while plutonium does not have an emission at 186 keV. Our measurements suggest that confirmation measurements should use a 3-sigma-above-background criterion for the presence of an emission and that one set of energy regions for the gamma-ray spectra is suitable for both applications.

2. Combined Thermal/Epithermal Neutron (CTEN)/TGS Package Monitor (K. L. Coop, R. J. Estep, and L. E. Ussery, NIS-6). We have previously reported on experiments to detect concealed SNM in containers using the CTEN interrogation technique.^{56, 57} As a follow-on to that report, this year we investigated another method of detecting partially shielded SNM that uses the differential attenuation of gamma rays in materials to flag the presence of significant gamma-ray shielding.⁵⁸ Depending on the particular facility or safeguards concern or both, one or more detection methods might be needed.

Specifically, we made a set of measurements and calculations to determine the effect of various shielding materials on the 375- and 414-keV gamma rays from ²³⁹Pu using the prototype TGS. This instrument has a 35% HPGe detector located 19.5 in. from the center of a 208-L drum. Varying thicknesses of lead were interposed between a 100-g, low-burnup plutonium cylinder and the detectors, and the ratio of peak heights was measured. MCNP calculations were made for the same thicknesses of lead and for selected thicknesses of some other potential shielding materials, including polyethylene, aluminum, and iron.

These measurements and calculations demonstrated that comparison of these peak ratios can provide very useful information about the presence (or absence) of significant quantities of shielding materials in close proximity to large quantities of plutonium. It seems clear that using a test of peak ratios for each TGS voxel would provide a sensitive and readily implemented means of detecting partially shielded plutonium in many waste screening situations. This should be combined with limits on the attenuation allowed for the transmission scan of each voxel or adjacent set of voxels, to increase the probability of detecting partially shielded plutonium in waste drums. These two checks would not significantly increase assay or analysis times. The basic information is routinely obtained in the TGS measurement. However, depending on the criteria used and the composition of the containers being measured, some increased number of "false positives" would be expected, thus resulting in the need to perform additional

measurements or analyses. These additional measurements or analyses might include real time radiography or the use of neutron-based systems such as the californium shuffler or CTEN instruments.

Additional measurements with newly built TGS and CTEN instruments at Los Alamos are planned for FY 1995 and FY 1996.

3. Neutron Multiplicity Counting (G. Brunson, NIS-6). This effort is directed toward a general improvement in counting neutron multiplicities and specifically to the development of software for passively counting neutron multiplicities in CTEN.

The target object for the procedure is the "gray barrel." This is a waste barrel about which we might know a little; for example, we might know that it originated at a site where the ²⁴⁰Pu content of plutonium is consistently about 6%. We would then assume that plutonium, if present in the barrel, would have that isotopic composition.

Three confounding factors hinder accurate plutonium assay:

1. Neutron absorption in the barrel may cause an underestimate of unknown magnitude.
2. Non-fission neutrons from the (alpha,n) reaction on light nuclei may cause an overestimate of unknown magnitude.
3. If, through carelessness or subversion, there is a lump of plutonium in the barrel, neutron multiplication in that lump will cause an error, which may be either up or down depending on the method of analysis.

Our objective is to find the vital unknown, the mass of plutonium, in the face of the three associated unknowns enumerated above.

During the past year, there were four major aspects of our work on counting neutron multiplicities:

1. We brought the "list" module into operation and adapted our software to that data source. The list module simply records the arrival time of neutron pulses (up to 106 events). The time resolution is 200 nanoseconds, but no pulses are lost if several neutrons arrive simultaneously. Our present analysis simulates, in software, the operation of our earlier shift register module. The subsequent analysis is essentially unchanged. The list module also allows us to examine the quality of counting channels (with respect to double-pulsing and dead-time recovery) to a degree not previously possible. The detailed look at dead-time behavior shows how we can significantly improve our software.

2. We adapted the list module software to gated operation so that we can acquire data during neutron burst interrogation in CTEN. Currently we are working on algorithms to use in analyzing such data.
3. In its current location (Los Alamos, TA-18, Bldg. 227, elevation 6700 f), CTEN has a background rate of 50 counts/s, almost all from cosmic rays. It has a sensitivity of 10 counts/s per gram for "ordinary" plutonium (that is, 6% ^{240}Pu). The background count rate varies inversely, 1% for each 1-mm change in barometric pressure. It is not uncommon to see a change of 10 mm when a storm front passes. Thus, we might see a background change of 5 counts/sec (10%) corresponding to 1/2 gram of plutonium. We have installed an electronic barometer, so that the background count taken at the beginning of a data run can be adjusted to the current pressure before being subtracted in the analysis.

4. MCA-465 Confirmation Instrument (P. E. Fehlau, NIS-6). We have been helping Rocky Flats adopt the TSA Systems MCA-465 PMCA as a confirmation tool. During this year, the major problems with the instrument were corrected (see Part 1, Sec. I.A.2), and Rocky Flats began routine use of the PMCA; they have been successful in using it with some help from the manufacturer to correct the remaining minor problems. Our assistance has been completed, although Rocky Flats would now like us to evaluate a new, more compact PMCA being developed by TSA Systems.

F. Improved Materials Control and Accountability for Nuclear Materials Facilities

Safeguards systems design and evaluation software demonstrated in this task will extend currently used tools to include the dynamic aspects of processes and safeguards and reduce the personnel effort for system assessments. This task also demonstrates anomaly detection concepts and software applicable to automated processes that will generate large amounts of safeguards-relevant information in the reconfigured DOE complex.

1. Anomaly Detector for Processing Facility (R. Whiteson, NIS-7; C. Baumgart and T. Tunnell, EG&G). Large amounts of safeguards data are automatically gathered and stored by monitoring instruments used in nuclear processing plants, nuclear material storage facilities, and nuclear fuel fabrication facilities. An integrated safeguards approach requires the ability to identify errors and anomalies in these data. Anomalies in the data could

be indications of error, theft, or diversion of material. The large volume of data makes analysis and evaluation by human experts very tedious, and the complex and diverse nature of the data makes these tasks difficult to automate.

The goal of our current project is to design a system that can use the information contained in safeguards data to identify invalid or anomalous events, states, or data. Our approach is to develop a tool or filter that will aid rather than replace the expert. Upon review by the expert, the data identified as anomalous can be validated or corrected. We are developing analysis tools to automate the anomaly/error detection process. Using data from accounting databases, we are modeling the normal behavior of processes. From these models, we hope to be able to identify activities or data that deviate from that norm. Such tools would be used to reveal trends, identify errors, and recognize unusual data. Thus, the expert's attention can be focused directly on significant phenomena.

The Material Accountability and Safeguards System (MASS) is a real-time, computer-based database system used by Los Alamos to document the movement and processing of SNM. Such movement and processing of SNM is characterized by a "transaction" that represents the basic entry in the MASS database. All transactions are entered manually by human operators and, hence, are subject to data entry errors. Process control and accountability staff regularly study transaction records to detect errors and discrepancies, a labor-intensive process.

Models of many of the MASS transactions exist in the form of flowcharts that guide the user on the proper way to enter a transaction into the MASS database. Because these models of transactions exist, we determined that a rule-based expert system would be the most efficient and effective method of detecting anomalies. We are using EXSYS, an expert system design package. Current and recent entries to the database consist of a subset of the historical entries and have been defined by the flowcharts. Thus, this is a logical place to begin developing an anomaly detection system. Using the flowcharts allows us to develop rules that apply to items that are being processed. It is our understanding that the flowcharts apply to a large subset of current entries and to a smaller subset of historical entries. Once we develop an anomaly detector that can detect anomalies in new entries, we can expand it to detect errors in the static inventory, which may be more difficult to do. A different approach will be needed for these entries. Possibilities include creating a rulebase in conjunction with the experts or using neural networks to create models of the remainder of the normal transactions. We must be careful not to train a system on errors. It may be necessary to have experts identify errors manually before we train.

We selected a related subset of flowcharts and coded the information they contained into the expert system rulebase. We developed rules based on four flowcharts. These are Hydroxide Cake Dissolution, Process Status CD;

Ion Exchange, Process Status RFX; Ion Exchange, Process Status LR; and Evaporator, Process Status EV. Figure 28 shows the flowcharts for the Evaporator Process. Our experience so far has indicated that between 9 and 15 rules are required to completely characterize each flowchart. As we developed the rules for the selected flowcharts, patterns began to emerge. Based on these patterns, we believe it will be possible to automate some of the rule generation.

We tested the performance of our expert system using transaction data from the MASS database from February 1994. There were 102 transactions for the four modeled Process Statuses. Our expert system found 53 of these transactions to be anomalous. We met with experts at the facility and resolved 52 of the anomalies. The resolved anomalies were the result of data missing from the flowcharts or our misunderstanding of the flowcharts. We have enhanced our rulebase to allow these types of transactions. The unresolved anomaly was a true anomaly; that is, an error in the database. The user had entered a valid but incorrect Process Status. The incorrect Process Status was inconsistent with the entered Lot ID, measurement type, and account number.

We are very encouraged by our preliminary results: that we correctly detected an error in the database and that all the false positives have been resolved. We believe that this type of anomaly detection system can be used effectively to detect errors and enhance the integrity of material and controls data. Our plan is to complete development of the rule-based system to model those data that are well understood, as defined by the flowcharts. The next stage

will be to complete the process by extending the model to incorporate other types of data. This is the more difficult aspect of the modeling process and will require the use of more sophisticated anomaly detection techniques.

G. Materials Control Technology T&E

The objective of this task is to demonstrate advanced nuclear materials control technology developed with particular attention to meeting the insider threat. The task includes the demonstration of improved vehicle and pedestrian portal monitor capability at operating facilities, the evaluation of portal monitor applications, the use of ARS as a materials control technique, and the use of digital image processing technology to enhance control of nuclear materials at DOE facilities.

1. **Multi-Processor Imaging (C. A. Rodriguez, NIS-7).** The EIVSystem is a video-based surveillance application designed to help reduce the frequency of physical inventories in domestic nuclear materials vaults and long-term stores. This surveillance system is CPU-based and configured with one or more CCD cameras, a hard-disk data store, and a tape archival system. The current implementation uses a Sun Microsystems SPARC architecture.

Data from the EIVSystem cameras installed in the vault or storage area are transmitted via fiber optic cable to a safeguards office complex. There the data are processed by the host computer, analyzed for events, and if an event is detected, it is video-recorded using wavelet transform

Fig. 28. Flowchart for the Evaporator.

image coding. The data are reviewed weekly by safeguards personnel to determine if any detected events have safeguards significance. For a description of the development of the EIVSystem see Part 1, Sec. I.B.

Recent availability of multi-processor SPARC computers has expanded the capabilities of the EIVSystem enormously. Originally a three-camera system, increase in processing power now enables the EIVSystem to host up to 18 cameras while maintaining a processing speed of less than one second per camera. For data review, where processing speed is required to reconstruct compressed images, an additional processor has been added to specially reconstruct the compressed images using digital signal processing.

2. Anomaly Detector for Item Facility (J. A. Howell, NIS-7). We are developing a model of an item facility for an MC&A application that will detect anomalous behavior. We have developed prototype software, which forms the basis of a simple model, to automatically review and analyze safeguards data from continuous unattended monitoring systems. This technology, based on pattern recognition by neural networks, provides significant capability to analyze complex data and has the ability to learn and adapt to changing situations. The concept is a new method to integrate spatial (digital video) with time (radiation monitoring) information.^{25, 59} Using this technique, we are able to distinguish normal material movements from abnormal activity.

To develop and evaluate this concept, we have established a test bed in a controlled radiation laboratory at Los Alamos. We use an array of sensors to monitor the movements of nuclear material within a storage area. A neutron detector is used to check the room for the presence of neutrons from exposed material. This detector (Detector #2 in Fig. 29) is located on the wall near the vault or holding area. Another neutron detector monitors an AWCC (Detector #1 in Fig. 29) for the presence or absence of material in or near the AWCC. Finally, a camera images a selected area around the vault. Changes in the scene are quantified using a metric (a pixel difference) that provides

motion levels as a function of time in addition to the spatially oriented video data. A diagram of the room is shown in Fig. 29.

An example of the integrated data is shown in Fig. 30. The neutron data are displayed as the number of counts per second as a function of time, and the video data are displayed as a pixel difference versus time. The pixel difference is calculated as the number of pixels that differ between the current scene and some baseline picture taken when there was no activity in the room. In Fig. 30, the lowermost data frame shows the camera pixel difference data for a 15-minute interval. The first data frame shows the neutron count data from the wall detector, and the next two data frames show the total and real neutron count data, respectively, from the AWCC.

Because the data are collected continuously, some method for identifying activity within the room had to be devised. Once an "event" is identified, then the anomaly detection network can be used to determine whether the event is normal or anomalous. In designing an event identification mechanism, we made the basic assumption that any activity "of interest" within the room would be indicated by an increased neutron count rate in the wall neutron detector. In other words, unless nuclear material is removed from the safe, no neutron data are recorded in the wall detector and, hence, the activity is not of interest. In a processing area, this may not be a valid assumption. We may want to key on a video event or some other data point.

Using the collected set of integrated test data and an event identification mechanism, we extracted events of interest from the data set. A number of features that characterize these events were then extracted to train and test the anomaly detection network. These features were calculated for each of the events (normal and anomalous) identified in the acquired data. The features were then incorporated into training and test data sets that were used to train the anomaly detection neural network.

A neural network was built to model the material movements and detect patterns. The performance of the network was excellent; all normal events were identified

Fig. 29. Diagram of the radiation laboratory for testing the various sensors, including the video camera, a neutron totals counter, a neutron coincidence counter, and a shield or vault for storing radioactive sources.

Fig. 30. A time expansion of a radiation event where the top pixel-difference curve shows the SNM custodian entering and leaving the ROI twice to remove the source from the shield and then to return it after the assay in the well detector.

as being normal and were effectively discriminated from the anomalous events. This means that none of the normal events were identified as anomalous (false alarms), and none of the anomalous events were identified as normal (errors). In addition, the neural network was able to discriminate accurately between the two types of anomalous events (the type B and type C events).

In summary, we have successfully developed a prototype neural-network-based anomaly detection system that is capable of discriminating between normal and anomalous nuclear material handling activities within a storage area. We have also completed a preliminary design for a production system.⁶⁰ Future work on this project includes the following:

1. optimizing the event-identification mechanism,
2. collecting additional data and training with it,
3. incorporating region-of-interest information into the anomaly detection neural network,
4. developing a system requirements and system design document for a fieldable anomaly detection system for a facility,
5. generalizing the network,
6. incorporating data filtering and compression techniques,
7. developing threshold values based on statistical techniques with the possibility of coupling multiple sensors to enhance the sensitivity of the system, and
8. designing an integrated sensor network with time synchronization between the radiation sensors and the video system.

See also Part 1, Sec. I.B and Part 1, Sec. I.E.2 for descriptions of the development of the digital video system and the technology development experiments.

H. Computer Simulation Development

Simulation is an essential tool for modeling the processes and safeguards systems that will compose the reconfigured DOE complex. Recent advances in commercial software and hardware have made it possible to develop much more flexible and versatile simulation tools. Los Alamos has developed a generic facility simulation (FacSim) model in response to process development needs. This same model provides a dynamic description of processing activities useful in analyzing safeguards and security issues. The generic nature of the model permits new facilities to be described by altering data sets rather than reprogramming the model; this results in faster and cheaper analyses of dynamic processes. This task has the following objectives: (1) provide a simulation model that can be used easily by facility personnel, (2) develop design and analysis tools that emphasize detection of insiders by MC&A elements, (3) use the model as a testbed for anomaly detection algorithms, (4) provide assistance to users of the model, and (5) explore further development of the model for application in other DOE initiatives.

FacSim/2.0 Batch Processing (A. C. Coulter, NIS-7). FacSim is a generic simulation program that we developed to model processing and safeguards operations for nuclear materials facilities. The original version of FacSim was written in the simulation language Simscript II.5 and described batch-processing operations. We used it to develop simulation models of all process operations at the LAPF and of major process areas at Savannah River and at Rocky Flats. FacSim was also used to evaluate processing and materials accounting features for several facility designs, including the Special Isotope Separation facility and a modular plutonium recovery plant.

Development was subsequently begun on a new version of FacSim written in C++ to operate under Microsoft Windows. Because of programmatic needs, the new version of FacSim was initially oriented towards simulation of continuous-flow processes such as those in reprocessing plants. The first applications of the C++ version of FacSim were to the design for the Rokkasho-Mura Reprocessing Plant (RRP) and co-denitration facility that are to be constructed in Japan. Consequently, there was an awkward situation in which the old version of FacSim only described batch-processing operations and the new version only described continuous-flow processes.

Fortunately, the task of implementing the description of batch-processing operations in the new C++ version of FacSim has now been completed. The implementation of the batch-processing description in C++ was not carried out by "transliterating" the original Simscript code to C++, but by rethinking and revising the data structures and representations as necessary to make full use of the distinctive features of the C++ language. The new program, which is called FacSim/2.0, also allows increased flexibility in describing and tracking material components and in describing process equipment. We have prepared a user's manual that tells how to use FacSim 2.0 to develop models of nuclear material processing facilities.⁶¹

I. Basic Systems Design and Integration

Continuing increases in the amount of material within the DOE complex, more stringent Environmental, Safety, and Health requirements, and limited resources for operational safeguards will require innovative approaches to maintain the quality of DOE safeguards and security activities. An important element in reducing costs while improving efficiency of safeguards is integration of materials control, materials accounting, physical protection, and operational activities such as process monitoring. Under this task we develop design methods and conceptual systems that demonstrate system integration prior to full-scale development.

1. LANMAS Information Exchange (J. Claborn, E. A. Kern, and M. J. Roybal, NIS-7; M. Boor, CIC-12). We held discussions with materials accountability personnel at the WSRC, Pantex, INEL, Los Alamos National Laboratory, SNLA, Oak Ridge Y-12 plant, WHC, and LLNL. These discussions helped to formulate the LANMAS requirements and to disseminate information to interested sites. Two LANMAS meetings were held: (1) a meeting in Naples, Florida, after the 1994 INMM meeting to discuss LANMAS development and (2) a meeting in Los Alamos to discuss the Software Requirements Specification. Both meetings were well attended.

2. LANMAS Computer Security (J. Claborn and L. Harris, NIS-7). The LANMAS Computer Security Requirements document⁶² was released. It is being

initially used for SNLA's implementation of LANMAS. We attended several Windows NT seminars to gather information on the implementation platform and were able to obtain a beta version of NT 3.5 for security testing. Many of the required security features are standard in Windows NT 3.5.

3. ARGUS Evaluation (J. E. Smith, NIS-7). ARGUS, a joint project of ANL-W, Los Alamos, and SNLA, is an integrated material accounting/materials control system running since 1991 at the ANL-W FMF.

The ARGUS system addresses the concept of real-time tracking of materials between workstations, the granting of authority, and auditing these movements within the facility. The most significant advantage of the ARGUS system is the degree of flexibility in its basic structure. Each subsystem—PC-DYMAC for material accounting, PAMTRAK for material control, and WATCH for material surveillance—can function alone. This suits the needs of a variety of users, who require different sets of capabilities.

PC-DYMAC had its share of problems during FY 1994. As the PAMTRAK interface was tested at SNLA and at ANL-W, several changes were made to correct the flow of transaction processing. Installation of the system in FMF was delayed by the curse of modern complex computer systems: defective hardware masquerading as a software problem. However, the interface performed in testing and initially upon installation according to design specs, which were produced for an SNLA predecessor to the PAMTRAK system.

ARGUS continues to meet DOE SNM reporting requirements in an operating fuel fabrication facility and to demonstrate the utility of microcomputer-based near-real-time accounting (NRTA) solutions based on microcomputers.

a. T&E of ARGUS Upgrade Software On-line at ANL-W. We tested and evaluated ARGUS, with special emphasis on the newly installed material control WATCH and barcode readers, throughout FY 1994. Testing will continue at ANL-W FMF, with ongoing software support from Los Alamos as needed. A preliminary evaluation of the PAMTRAK system and its interface with PC-DYMAC was produced by ANL-W. A full evaluation will be issued after the system has been used in the facility on a regular basis for some months.

b. Identifying ARGUS Portability Issues. The report by Smith and Bearse⁶³ examines the technical issues involved in porting the core PC-DYMAC system and its Xenix-based descendant, ARGUS, between computers, operating systems, and facilities. Support was provided to ANL-W in the porting of PC-DYMAC to a stand-alone system for material accounting and report generation in another facility at ANL-W.

III. MC&A FULL-SCALE DEVELOPMENT

A. NDA Technology Commercialization and Joint Development

The objective of this task is to transfer NDA technology by developing commercial suppliers of NDA instrumentation, enlisting industry participation in NDA detector and instrumentation development, and providing consultation and design information on assay systems to commercial vendors.

1. **Passive Neutron Assay System Cooperative Research and Development Agreement (CRADA) (M. M. Pickrell, NIS-5).** We have just completed the negotiations for a \$1.4 million CRADA between our Safeguards Assay Group and Canberra Industries, Inc. The CRADA has received both preliminary and final DOE approval and a DOE Category Exclusion for NEPA (National Environmental Policy Act) certification. It has been approved and signed by both laboratory managements. Los Alamos National Laboratory Director Sig Hecker and Canberra Chief Executive Officer George Serrano.

This CRADA allows Canberra and Los Alamos to jointly develop the next generation of passive neutron assay system for containerized waste. Important features of this system are as follows:

1. Passive neutron assay for a largely matrix-insensitive and isotope-insensitive measurement. (Passive systems are also intrinsically more reliable and simple than active systems.);
2. Add-a-source matrix correction to improve matrix compensation;
3. Coincidence and multiplicity neutron counting for a direct measure of the plutonium content independent of the (alpha, n) rate, and additional matrix compensation;
4. Cosmic-ray veto for background suppression and improved sensitivity;
5. Statistical filter for background suppression and improved sensitivity; and
6. High-efficiency neutron detectors for improved sensitivity.

The objective of this CRADA is to develop an instrument that extends existing safeguards technology so it can be effectively applied to assay containerized waste for environmental and waste management. An important feature of the CRADA is that the industrial support and collaboration will enable the development of technology that would otherwise not have been possible. The construction and development cost for this instrument exceeds \$1 million and is not funded. However, because the industrial partner is bearing the construction cost, the project cost to

the DOE becomes modest and is funded. Both the DOE and the industrial partner will share the benefits from the developed technology.

2. **Technology Transfer for the M³CA (J. K. Halbig and P. A. Russo, NIS-5).** We are actively pursuing several avenues for commercializing the Los Alamos-developed handheld M³CA. We have met with several electronics manufacturing companies and helped them analyze costs and markets for this technology. Our goal is to have the technology transfer process underway by the end of CY 1994, with an initial version of the unit available for sale by private industry in late 1995.

3. **Transfer of Coincidence and Multiplicity Software to Private Industry (S. C. Bourret, NIS-5).** We have expedited and completed transfer to Canberra Industries, Inc., of the neutron coincidence counting programs NCC (for conventional passive coincidence counting) and MULTI (for passive neutron multiplicity counting) and the associated software manuals and documentation for users. These codes will be used with the new Canberra 2150 multiplicity shift register module developed by Canberra under technology transfer from Los Alamos.

4. **Neutron Multiplicity Counter Technology Transfer (M. S. Krick, NIS-5).** The Los Alamos neutron multiplicity electronics and software mentioned above can be used with any thermal neutron counter, but the performance is much better when used with a counter designed as a multiplicity counter. The first neutron multiplicity counter design package transferred to private industry is the Plutonium Scrap Multiplicity Counter, a relatively small-bore, high-efficiency design. Canberra Industries has requested this design and is planning to offer it for sale to domestic and international customers. Other neutron multiplicity counter designs will become available for technology transfer as they are tested and documented.

5. **Transfer of Solution Assay Instrument Technology (S. T. Hsue, NIS-5).** Five Solution Assay Instruments have been installed at the LAPF, and documentation on the technology has been transferred to Canberra Industries at their request. Each of these five units has an electronics module to control the shutters of the transmission source. Some of the earlier control modules were rack mounted. Because space is at a premium at LAPF, the control modules were redesigned and repackaged into four-wide nuclear instrumentation modules. The new control module technology is also available for technology transfer when needed.

6. **Support to the Small Business Innovative Research (SBIR) Program (P. A. Russo, NIS-5).** We have encouraged the SBIR technology development process by

initiating joint interactions, where appropriate, with some of the successful small business winners in areas such as joint evaluation of detectors or integration of new detectors with existing Los Alamos technology.

In cooperation with several manufacturers of room-temperature gamma-ray detectors, we have obtained several of their new gamma-ray detectors and examined them in the laboratory. Similar tests are being discussed with other manufacturers. The detectors are all compact spectroscopy-grade prototypes that operate at room temperature. Included in the recent laboratory activities to date are several types of Cd(Zn)Te detectors, plus a CsI/HgI₂ photodetector, a HgI₂ photodetector, and a HgI₂ detector. Further investigations of new CdTe, Cd(Zn)Te, and CsI/HgI₂ detectors are planned.

In these interactions, we served as a user facility for testing and evaluating the technology developed by the SBIR grant winner. Prototype detectors for gamma-ray spectroscopy were set up with gamma-ray data acquisition

equipment. Gamma-ray spectra of nuclear materials suitable for characterizing the detector's performance and representative of the measurement needs called out in the SBIR request for proposals (HEU and plutonium of various burnups) were obtained in the laboratory. We exchanged data and information, particularly with regard to optimization of design to suit measurement needs for arms control, nonproliferation, and security. Additional interactions with the above-mentioned SBIR winners and others are anticipated.

7. Transfer of Shuffler Technology (M. M. Pickrell and P. M. Rinard, NIS-5). The technology for shufflers used in assaying 208-L waste drums has been transferred to Canberra Industries, Inc.,* and three units have been built (Fig. 31 shows the first two of these units).

*Canberra Industries, Inc., 800 Research Parkway, Meriden, CT 06450.

Fig. 31. The first two shufflers built by Canberra, shown in partially disassembled states.

A competitive bidding process was followed to select the company on the basis of their technical and sales capabilities.

The first two shufflers were delivered to Los Alamos, and the third will soon be delivered to LLNL. These three shufflers join three similar shufflers that have been in service within the DOE complex for several years.

B. MC&A Technology Training

The DOE MC&A Training Program is a major vehicle for technology transfer to both the domestic and international nuclear communities. Since 1973, the Los Alamos safeguards technology training program has grown from a single course to the present available curriculum (which includes eight formal seminar offerings and special lecture series) and has serviced more than 2500 students. The program is very successful both in informing participants of the latest nuclear materials control and measurement technology and in keeping Los Alamos Safeguards Research and Development (R&D) personnel abreast of the needs and experiences of facility operators and safeguards inspectors. The training program enjoys an excellent reputation throughout the domestic and international nuclear communities.

This year, our domestic training program comprised five seminars, extensive development efforts on the "NDA Techniques for Safeguards Practitioners" seminar, development of a draft syllabus for a "Waste and Residue NDA

Measurement" seminar, and participation on development teams and as instructors for new MC&A courses at the Central Training Academy (CTA).

1. **Los Alamos Safeguards Technology Training (H. A. Smith, NIS-5 and D. Wilkey, NIS-7).** Attendance at the five seminars presented at Los Alamos is summarized in Table V.

a. **Seminar on NDA Techniques for Safeguards Practitioners (H. A. Smith, NIS-5).** The Los Alamos Safeguards Assay Group presented two back-to-back offerings of the five-day seminar on NDA Techniques for Safeguards Practitioners on September 19-23 and 26-30, 1994, to a total of 55 students from 20 facilities. This course continues to exhibit the highest and most aggressive demand, which is backlogged with a waiting list of about 120 applicants. The two consecutive offerings allowed a higher rate of service to our large waiting list with minimal cost impact. This seminar, formerly called the "Fundamentals of NDA," provided detailed hands-on instruction in the use of gamma-ray and neutron NDA instrumentation for DOE safeguards personnel who perform nuclear material NDA measurements in their facilities. New curriculum upgrades for these offerings of the seminar emphasized the neutron laboratories, with the addition of some introductory material on neutron multiplicity counting.

Attendee Affiliation	Materials Accounting 3/21-25	Advanced Gamma-Ray Assay 5/2-6	In-Plant Holdup 7/11-15	NDA for S/G Practitioners 9/19-23	NDA for S/G Practitioners 9/26-30	Totals
Argonne West (Idaho)	1	1	1			3
Babcock & Wilcox (Lynchburg)					1	1
Brookhaven National Lab	1	1			1	3
DOE (All field offices)	1			2	2	5
DOE Headquarters	3			1	1	5
EG&G (Idaho)	1			1		2
EG&G (Rocky Flats)			1	2	2	5
EG&G (WAMO, Maryland)				2		2
GE Wilmington	1					1
LLNL	4	1		1	1	7
Los Alamos (Pu Facility)	3	4	4	3	2	16
Los Alamos (Other areas)	8	1	6	3	3	21
MMES, Oak Ridge K-25			2	2	2	6
MMES, Oak Ridge Y-12	1	1	1	2	2	7
MMES, Piketon		3		2		5
MMES, Paducah				1		1
Mound Laboratory				1		1
New Brunswick Labs	1				2	3
US NRC	1					1
Pantex	3					3
Sandia Labs, Albuquerque	1	1			1	3
Waste Isolation Pilot Plant (WIPP)			1			1
Westinghouse Hanford		2	2		1	5
Westinghouse Idaho		2			3	5
Westinghouse Savannah River	3	6	5	3	5	22
Korean Atomic Energy Research Inst		2				2
Aldermaston			1			1
TOTALS	33	25	24	26	29	137

b. Seminar on Materials Accounting for Nuclear Safeguards (D. Wilkey, NIS-7). The Safeguards Systems Group presented the seminar on Materials Accounting for Nuclear Safeguards on March 21-25, 1994. Thirty-three individuals participated in the seminar. Although most of the participants were from DOE and DOE contractor organizations, they included one person from the Nuclear Regulatory Commission (NRC) and two foreign nationals. The foreign national participants were from the People's Republic of China and Japan. Both of these individuals are working at Los Alamos with the Safeguards Assay and Safeguards Systems Groups.

c. Seminar on Measurement of In-Plant Nuclear Materials Holdup (H. A. Smith, NIS-5). The DOE-sponsored seminar entitled "Nondestructive Assay of Special Nuclear Materials Holdup," was presented at Los Alamos on July 11-15, 1994, to 24 attendees representing 10 facilities. The course was compressed into three days and still involved one-half day of introductory lectures, small-group hands-on measurements with portable NDA equipment, and "hands-on demonstrations" of upcoming technologies for automated portable NDA of holdup. The small-group hands-on measurements portion of the holdup school involved calibration of compact, low-resolution gamma-ray (NaI) detectors for assays of uranium and plutonium holdup in generalized (point, line or area) geometries, followed by measurement and quantitative assay of uranium and plutonium in simulated holdup exercises. The simulations were achieved with sealed uranium and plutonium reference materials inserted into piping, ducts, tanks, valves, and blenders (a total of 15 individual pieces of equipment with simulated holdup) in geometries similar to those of actual holdup deposits. All attendees performed the uranium and plutonium calibrations and measurements in two separate periods at two safeguards laboratory locations. The (NaI) calibrations, measurements, and quantitative assays were performed manually during these two periods. Some of the plutonium measurement exercises were also performed with a previously calibrated, automated HPGe system, and some were also done with a new, reconfigured portable neutron coincidence collar. The "hands-on demonstration," scheduled between the uranium and plutonium measurement periods, let the attendees experience a practical solution to extending the "laboratory" problem to plant-wide proportions; namely, a thousand-fold expansion in the required scope of holdup determinations.

d. Advanced Gamma-Ray NDA: On May 2-6, 1994, we hosted another offering of our "Safeguards Technology Training Seminar on Advanced Gamma-Ray Techniques of Nondestructive Assay of Nuclear Materials" for 25 students from 12 facilities. The subject matter of the seminar included high-resolution gamma-ray spectroscopy applied to transmission-corrected passive gamma-ray assay, uranium enrichment assay, and plutonium isotopic analysis.

2. Draft Syllabus for a Waste and Residue NDA Measurement Course (C. W. Bjork and N. Ensslin, NIS-5; and R. Likes, Fort Lewis College, Durango, Colorado). We are developing a new training course on "Waste and Residue NDA Measurements." A number of important waste characterization issues are associated with DOE waste acceptance criteria. There are also safeguards and security issues associated with the measurement of radioactive waste and residue materials.

The objective of the course is to help DOE facility personnel apply NDA techniques to address as many of these issues as feasible. The goals of the course are to demonstrate the use of NDA radiation measurement techniques and instruments for determining the masses of important radioactive constituent nuclei in radioactive waste and low-mass process residues, to indicate the interface between nuclear safeguards and radioactive waste management, and to emphasize the difficulties in measuring the many forms of low-level and transuranic waste that have been generated. High-level waste assay will not be addressed.

We believe the course will be of interest to experienced radioactive measurement technicians who operate waste assay instruments and to their technical supervisors, auditors, and regulators. Potential benefits of the course are faster and more cost-effective waste characterization and nuclear material safeguards through the use of state-of-the-art NDA measurement technology. This will be achieved through the transfer and sharing of waste measurement technology information between national laboratory staff, DOE facility operators, and private industry.

We have prepared a draft syllabus based on a four-and-one-half-day course. The heart of the proposed course will consist of three modules, each covered in one day (about six contact hours per day) and focused around actual instruments used to assay radioactive isotopes in 208-L drums:

1. Segmented Gamma-ray Scanner (SGS)—Tomographic Gamma-ray Scanner (TGS);
2. Neutron Coincidence Counter (NCC), Add-a-Source, and Californium Shuffler; and
3. Differential Die-away Technique (DDT)—Combined Thermal Epithermal Neutron Interrogation (CTEN) combined with a demonstration of Real-Time Radiography (RTR).

Each training module will cover topics such as calibration procedures and use of standard reference materials; matrix effects, limitations, and corrections; response variation caused by radioactive material distribution within the waste drum; sensitivity; lump effects corrections; isotope identification/ratios; and scope of the techniques with respect to waste forms and limitations. Additional input from DOE/OSS, DOE/EM, and the waste generator sites on school content is welcome.

3. MC&A Training Support to the CTA (T.E. Sampson and H.A. Smith, NIS-5). In a continuing effort begun in FY 1992, two Safeguards Assay Group staff members served as instructors for two CTA MC&A courses: "Basic MC&A Measurements" (MCA 140) and "Basics of Measurement Control" (MCA 144). Both staff members served on the course development teams the previous fiscal year.

C. Independent Validation and Verification (IV&V) (W. J. Huntman, NIS-12)

A design phase IV&V was completed on the Integrated Computing Network (ICN) at Los Alamos. This network is a new design that separates the classified and open computing resources into two partitions with common services, such as printing, residing on a multilevel backbone network.

The design phase IV&V consisted of reviewing numerous documents and interviewing the designers and project managers. The IV&V team validated its understanding of the proposed design by developing its own view of the network architecture and then confirming the view with the designers. An unclassified report documenting the results of the IV&V was prepared and distributed to the IV&V team members and Los Alamos. The report is available to interested parties. Planning for the test phase of the IV&V on the ICN was initiated during October 1994. The test phase IV&V is now scheduled for February 1995 to coincide with completion of the network implementation.

An IV&V was completed on the Nuclear Emergency Search Team (NEST) Inter-agency Information Network for NEST Field Operations (IINFO). Although the IINFO network did not require a formal IV&V according to DOE orders, all organizations involved agreed that an IV&V should be conducted on the network. The IV&V was expected to provide additional assurance that the network would maintain the information separation and protection during the high-stress environments encountered when the NEST team is deployed. The IINFO IV&V was conducted during July 1994. The IV&V report was completed and distributed to the NEST organizations in October 1994. An IV&V was performed and the IV&V report completed for the LLNL Uranium Demonstration System. The UDS contains a one-way link designed as an information diode to restrict information flow from a secret restricted data computer system to an unclassified computer system.

D. Technology Exchange and Implementation

The objective of this task is to provide a focal point for transfer of integrated safeguards technologies to DOE processing and storage facilities. The task supports guidance, assistance, and training to assure that technology developed through the DOE safeguards R&D program is successfully implemented at DOE sites.

1. Technical Assistance to DOE Headquarters (N. R. Zack, D. D. Wilkey, K. E. Thomas, and B. R. Erkkila, NIS-7). The Los Alamos Safeguards Systems Group continued to provide timely technical expertise to support the DOE's OSS personnel as requested and required. Areas of support involved the in-depth materials handling and control experience offered by the group and the special capabilities for specific applications and cost-effective implementation of policy and guidance issued by OSS. As requested by OSS, personnel provided direct support to the Safeguards and Security (S&S) Divisions of DOE Field Offices. In many cases, assistance was provided to OSS on an informal basis; however, specific areas formally addressed included the following issues:

- SNM inventory difference analysis for the years 1946 to 1994,
- safeguarding of nuclear materials in waste,
- risk management and the vulnerability assessment process,
- DOE Order 5633.3B and its implementation guide with emphasis on chapters concerning the measurement of holdup and measurement control,
- procedures for termination of safeguards for DOE-Chicago waste nuclear materials,
- disposal of plutonium-bearing sludges by cementing,
- plutonium removal and handling procedures,
- safeguards on nuclear waste at DOE-Oak Ridge facilities,
- request for determination of foreign research reactor spent fuel category and attractiveness level,
- clarification on measurements policy for category IV-E material balance areas,
- discard of SNM from the Savannah River Site (SRS)-SED facility, and
- attractiveness-level requirements for "gunk" solutions.

Safeguards Systems Group personnel also functioned as the safeguards representative on the OSS Security Working Group and provided input to the preparation of the new physical protection order. The DOE MC&A and the physical protection orders were compared to provide assurance that the orders are in agreement concerning the control and protection of nuclear materials.

2. Neutron Users Group (N. Ensslin and P. M. Rinard, NIS-5). During the past year, two Neutron Users Group meetings were held with safeguards instrumentation developers, neutron instrument users, and representatives of commercial companies. The Neutron Users Group is supported by the OSS Technology Development Branch to provide a forum for exchanging information on neutron

NDA techniques and needs. The first FY 1994 Neutron Users Group meeting was held in conjunction with the January 1994 ASTM meeting in San Francisco. This provided an opportunity to meet with safeguards measurement personnel who are involved in preparing ASTM standards on NDA. The second meeting was held at the July 1994 INMM meeting in Naples, Florida. This meeting focused on inventory verification issues at DOE facilities, neutron NDA applications at the Y-12 plant, and the use of combined neutron/gamma-ray assay systems. After the regular Neutron Users Group meeting, a second meeting was scheduled for the next day to provide a workshop on the new neutron multiplicity measurement technique.

3. Radiation Detection Panel Meeting (N. Ensslin, NIS-5). On behalf of the OSS Technology Development Branch, one staff member of the Los Alamos Safeguards Program attended the September meeting of the DOE Radiation Detection Panel, chaired by Mike O'Connell of NN-21, to give a talk on radiation measurement programs sponsored by OSS. The talk provided an overview of OSS project lifecycles on measurement technology at Los Alamos and other national labs, with emphasis on the end-use customer and the technology transfer status.

4. Participation in the NDA/Nondestructive Examination (NDE) Interface Working Group (M. Pickrell, NIS-5). Several staff members of the Los Alamos Safeguards program attended the WIPP NDA/NDE Interface Working Group meeting in Carlsbad, New Mexico, on October 4-6, 1994. The meeting was hosted by the DOE Carlsbad Area Office and the Westinghouse Waste Isolation Division under the National Transuranic Program Office. The meeting included a number of excellent talks on NDA and a tour of the WIPP facility. Of particular interest is the upcoming Performance Demonstration Program, which involves the fabrication of waste drum standards and their use in demonstrating the performance of neutron and gamma-ray-based waste assay instrumentation. Waste assay instrumentation throughout the DOE complex is often used for both safeguards accountability and waste characterization, and most of this instrumentation has been developed by the OSS Technology Development program. The Performance Demonstration Program will provide a valuable comparison of various assay instruments and make it easier to determine whether they meet both safeguards and waste characterization criteria.

5. ARS Intrinsic Seals (C. T. Olinger, NIS-7). All containers for SNM can vibrate at a number of natural frequencies. These natural frequencies reflect a complex function of the container geometry and a number of parameters of the fill material such as its volume, acoustic velocity, density, viscosity, and amount of contamination. ARS measures these natural frequencies by exciting the body with one transducer and listening for the vibrational response with another. A range of frequencies appropriate

for many containers of interest is swept in just 10 s, and the acoustic spectrum is accumulated and displayed in real time by the ARS system, which is incorporated into a lap-top computer. These features combine to make the system highly portable and allow rapid, reproducible measurements.

No two acoustic spectra from different containers are ever exactly alike. Therefore, ARS can "fingerprint" filled containers and establish intrinsic seals. Containers can be identified by their ARS fingerprint. In the intrinsic seal application, it is possible to determine whether the container has been opened or contents removed by comparing a fresh spectrum to the reference spectrum for that container. This comparison between spectra is easily understood when it is reduced to a single number that is normalized to be between zero and one. Figure 32 shows the population distributions established for one method of comparing spectra. This result represents an optimized case, where the containers were in an air conditioned room and the containers were not disturbed between measurements, except when "tampering" was intentionally introduced. In this situation we observe clean separation between the cases where tampering occurred between measurements and where tampering did not occur between measurements.

We originally planned to begin field testing of ARS during FY 1994, but we found that a number of effects that might be found in a normal operating environment might alter the acoustic signature even when tampering does not occur. A high false alarm rate would result, so we felt that it was necessary to test these conditions before field testing began. Understanding what conditions adversely affect the ability of ARS to monitor a container's intrinsic seal would then constrain the most appropriate environment for field testing.

Laboratory-scale tests performed during FY 1994 centered around the questions of how sensitive the ARS technique is to container movement, transducer placement, thermal cycling, and differences between operators. Generally, we found that ARS is sensitive to all of these variables.

When no tampering occurs, the reproducibility of spectra between measurements degrades to varying degrees if care is not taken to replace the transducers to the same location where the baseline measurement was taken, when containers undergo thermal cycling, and even when containers are simply moved in a room and returned to their original location. Figure 33 shows the distribution for which no tampering occurred between measurements, but the container was subjected to thermal cycling of approximately 17C°. Conceptually, this distribution is analogous to the peak to the right of Fig. 32, but there is now overlap with the condition for which tampering did occur.

Because this intrinsic seal technique is sensitive to thermal cycling and movement of containers, it is probably best to perform field testing in a vault used for long-term storage that does not undergo large temperature swings.

Fig. 32. Quantitative comparison of spectra in cases where tampering occurred between measurements (left population) and where there was no tampering between measurements (right population).

6. FRAM Plutonium Isotopic Analysis System Development (T. E. Sampson, NIS-5; T. A. Kelley, CIC-12; D. Delapp, EG&G Los Alamos; and R. Friar, NIS-5). The FRAM plutonium isotopic analysis software analyzes the gamma-ray spectrum from plutonium samples and produces, without calibration or standards, a complete isotopic distribution of the plutonium, americium, and other isotopes in the sample. This code is the most versatile of its type in use in the worldwide safeguards community. We are developing several improvements and additional applications that will enhance its usefulness to the safeguards community.

We have released the first version of a new PC-based isotopic analysis system (PC/FRAM), which is coded in C

and runs under Windows 3.1. This popular interface is more acceptable to users than the old VAX-based system. We have numerous applications planned for this new software. One of the first applications is a mobile system, supported in part by facility funding, to be used at the LAPF. This system, shown in Fig. 34, can be wheeled around the facility allowing analysis of samples within gloveboxes without the need for bagouts or movement to a central count room facility or both.

The main thrust of new applications for FRAM and PC/FRAM has been its use with a single coaxial HPGe detector. Plutonium isotopic analysis systems using a single detector have historically used small planar germanium detectors, favored for their very high resolution which is

Fig. 33. Thermal cycling between measurements (gray population) reduces the ability to distinguish between cases where tampering has occurred (white population on the left) and cases where tampering has not occurred (white population on the right) for some comparison algorithms.

needed for sophisticated peak-fitting analysis. Some isotopic analysis systems add a second detector, usually coaxial, to improve the measurement results at higher gamma-ray energies. This second detector adds additional cost and complexity—attributes not desired in a production facility.

Our approach has been to demonstrate that a single coaxial detector can produce measurement results comparable to those of a single planar detector or a more complex two-detector system. We have successfully tested the mobile PC/FRAM system shown in Fig. 34 with a single coaxial detector of approximately 25% relative efficiency. These tests demonstrated that a single coaxial detector can produce results for the effective specific power used for calorimetry that are essentially equivalent in both precision and accuracy with those from a planar detector. The data in Fig. 35 were taken in 8192 channels at a gain of 0.125 keV/ch. Analysis of these data was confined to the energy range from 120-450 keV.

One of the principal advantages for a plutonium isotopic analysis system using a single coaxial detector is its ability to "see into" thick-walled or shielded containers and analyze the higher energy gamma rays that escape. Conventional planar detector systems usually analyze data below 400 keV and require data either from the 100-keV region or the region from 150-165 keV to provide a complete isotopic analysis. In thick-walled or shielded containers, these low-energy gamma rays do not escape from the con-

tainer and conventional planar detector analysis is impossible. A single coaxial detector can acquire and analyze data in the energy region above 200-300 keV up to above 1 MeV. These gamma rays usually escape from storage containers and can be analyzed to also provide a complete isotopic analysis. Data from planar detectors cannot be analyzed at higher energies because the measurement efficiency of the detectors is too low to provide reliable data. PC/FRAM in conjunction with a single coaxial detector is the only isotopic analysis software able to perform this analysis. We are perfecting this analysis to minimize its bias, but its general success has been proven with coaxial detector data taken on lead-shielded samples. The use of this analysis capability of PC/FRAM in facility operations will reduce operator radiation exposure because shielded samples will no longer have to be unpacked before measurement. The new capability will also enhance the ability to measure items in thick-walled storage containers necessary for arms control, nonproliferation, and treaty verification applications.

In addition to the application at the LAPF, several other applications and evaluations of PC/FRAM are planned for SRS, the United Kingdom, European Atomic Energy Community (EURATOM), International Atomic Energy Agency (IAEA), a plutonium storage facility in Russia, and a demonstration MC&A system in Russia.

Fig. 34. A mobile PC/FRAM plutonium isotopic analysis system.

7. Support to DOE Facilities on Inventory Verification (J. K. Sprinkle, Jr., P. A. Russo, and M. S. Krick, NIS-5). During FY 1994, we continued to provide support to many DOE facilities on inventory verification, shipper/receiver confirmation measurements, and initial NDAs of previously unmeasured inventories. Working with the Savannah River DOE MC&A Office, we prepared a schedule and budget proposal for the installation and integration of several NDA instruments into a measurement system for 208-L drums of mixed plutonium/uranium scrap.

At the Oak Ridge Y-12 plant, with additional support from the DOE Field Oversight Office, we provided technical support to the MC&A team studying inventory difference issues in several uranium scrap and waste processing areas. We are currently working with Y-12 to see if additional capabilities could be provided for portable, gamma-ray-based isotopic analyses in these process areas to reduce potential inventory differences. We also reviewed an Oak Ridge proposal to construct calibration materials for gamma-ray-based measurements of waste in 4 ft x 4 ft x 6 ft boxes or 208-L drums. The calibration materials will be constructed in a modular fashion to allow minimal amounts of SNM to be used. We continue to work with Y-12 count room personnel on active multiplicity measure-

ments, and we are currently analyzing an initial set of data received from Y-12 on skull oxide containers, an important SNM category at Y-12.

We continued to interact with the LLNL MC&A organization, which is currently acquiring additional NDA instrumentation for inventory verification measurements. Livermore has acquired an AWCC from Idaho, and we provided support on calibration. Livermore also is procuring a californium shuffler for high-density waste drums from Canberra Industries and a 30-gal.-drum neutron multiplicity counter from Los Alamos for large plutonium items.

At Rocky Flats, the EG&G management team and the Los Alamos Technical Office have begun a program of collaboration with Los Alamos to provide support to Rocky Flats on SNM disposition and environmental remediation. In the area of MC&A, an NDA Assessment Team has been established to work with Rocky Flats safeguards personnel to identify NDA measurement needs at Rocky Flats. Additional funding has been obtained from Rocky Flats to support the work of this team.

8. Support to DOE Facilities on Holdup Measurements (P. A. Russo, NIS-5). We have continued to work with Y-12 personnel to apply the new Los Alamos

Fig. 35. Single-coaxial-detector data from PC/FRAM showing freedom from bias and spread in average values comparable to planar detector data.

M³CA to holdup measurements at the Y-12 facility. Two prototype units are undergoing evaluation by Y-12 safeguards personnel, and these users demonstrated their holdup measurement procedures and data acquisition software during the July 1994 In-Plant Holdup Measurement Seminar at Los Alamos. We have also provided support to Savannah River on holdup measurements of PuF₄, to Hanford on process-filter holdup determination, and to Rocky Flats on NDA of raschig-ring-filled solution tanks. With additional support from the INEL, we completed a conceptual design study for holdup measurements of Rover fuel, both *in situ* and after removal and packaging into containers.

9. Support to DOE Facilities on IAEA Inspections of Excess Weapons Materials (J. E. Stewart, NIS-5). DOE facilities are beginning to undergo IAEA inspections of their excess weapons materials, and the IAEA will be using AWCC, neutron multiplicity counters, and possibly calorimeters developed by OSS to verify the SNM content of these materials. We are supporting these facilities by providing procurement specifications for instruments, providing instruments on short-term loan, or providing help with calibration and data interpretation. These activities are ongoing, or imminent, at Y-12, WHC, Rocky Flats, and Savannah River.

The first round of IAEA inspections took place in September at the Y-12 Tube Vault. Two AWCCs, one provided by the IAEA and one loaned by Los Alamos, were used to measure uranium metal castings, each of which contained about 18 kg of ²³⁵U. About 40% of the uranium in the vault was measured by the IAEA, and the AWCCs verified the ²³⁵U content to approximately 0.4%. These good results will greatly reduce the amount of sampling and destructive analysis required at Y-12 to meet IAEA requirements.

10. Support to DOE/OSE Study on Fissile Inventory Assurance (N. Ensslin and T. Sampson, NIS-5). With additional support from the DOE Office of Security Evaluations, we have provided technical data, figure illustrations, and technical consultation to the DOE report on "Increasing Fissile Inventory Assurance within the US Department of Energy." Areas of discussion included NDA measurement methods and their accuracy, measurement techniques for scrap materials, and hardware and software standardization issues.

11. Preparation of NDA Application Notes (N. Ensslin, NIS-5). In FY 1994, we completed Application Notes on several new NDA technologies. An Applications Note entitled "Passive/Active Neutron Coincidence Counter" (LALP-93-31) was published on an instrument developed by the OSS Technology Development Program, and now in use at the LAPF (TA-55), for assay of items containing plutonium, uranium, or both. Application Notes on the new NDA techniques for FRAM isotopic analysis

and neutron multiplicity counting were also completed and printed and are now being distributed. We also prepared a draft Applications Note on the Integrated Holdup Measurement System, based on the miniature hand-held MCA and the generalized-geometry software package, for circulation and review.

12. Support on Addressing Difficult-to-Measure Materials (J. K. Sprinkle Jr., R. Siebelist, NIS-5; C. J. Garcia, J. Martinez, L. Trujillo, NIS-6). We supported DOE/OSS in preparing guidance documents for addressing difficult-to-measure materials and have applied some of these concepts to field applications in uranium vaults. The guidance for situations for which difficulties preclude typical measurements is to use two different attributes such as heat, neutrons, gamma rays, or weight to establish the presence of the desired SNM. The concept of a double confirmation measurement for difficult-to-measure items must take into account the weak passive neutron and heat emissions from uranium. Consequently, the two measurements must both be based on gamma radiation when weight measurement is not practical or no initial weight is documented. Our measurements suggest that confirmation measurements for difficult-to-measure items should use a 3-sigma-above-background criterion for the presence of an emission. The presence of HEU is indicated by a strong emission at 186 keV, a weak emission at 1001 keV, and an emission at 2614 keV. The presence of LEU is indicated by emissions at 186 and 1001 keV, and no emission at 2614 keV. We plan to automate this identification process using software tools so that the application of this procedure does not require a gamma spectroscopy expert.

13. Vehicle SNM Monitor Applications Guide (P. E. Fehlau, NIS-6). We are revising our 1987 Vehicle SNM Monitor Applications Guide⁶⁴ because of the increased development and use of the monitors since that guide was written. During this year we reviewed material that might be included in a revised guide and began outlining the report.

14. Support on SNM Portal Monitoring (P. E. Fehlau and D. A. Rutherford, NIS-6). We continue to provide assistance to DOE and its contractor facilities with procuring, maintaining, and properly using and evaluating SNM monitors and confirmation instruments. This year we provided general support by purchasing and distributing a booklet containing all of the SNM portal monitoring standards published by the ASTM. We later responded to additional requests for the booklet from operations offices and manufacturers. We also provided the following assistance to the field.

DOE/Albuquerque. We responded to a request for assistance in recovering a thorium source as part of a remediation effort by providing information on

the capabilities of SNM portal-monitoring equipment that might be used for locating the source.

Nevada Test Site. We consulted with Nevada Test Site maintenance personnel on problems with a vehicle SNM portal monitor that resulted from lack of periodic preventative maintenance.

Support for the Former Soviet Union (FSU). We provided information on commercially available SNM monitors on several occasions and also prepared or procured SNM monitoring equipment for demonstrations of the equipment both in the US and in FSU countries.

Los Alamos. We discussed SNM monitor performance and the ASTM performance standards with personnel from operational security and provided batch assay and mass spectrometry documentation for the standard HEU test sources that we had provided to them.

Shonka Research Associates, Marietta, Georgia. We provided information on calibration and evaluation of one of our vehicle SNM monitors.

DOE/OSS. We provided comments on the portal monitoring aspects of a draft "Guide to Detection Element Assessment for DOE Order 5633.3B."

Part 2. International Safeguards

PART 2. INTERNATIONAL SAFEGUARDS

I. SYSTEMS STUDIES AND SAFEGUARDS DESIGN

A. Design of a New Portable Fork Detector for Research Reactor Spent Fuel (S. -T. Hsue, H. O. Menlove, and P. M. Rinard, NIS-5)

1. Introduction. Many times in nonproliferation and international safeguards one needs to verify spent research-reactor fuel. Special inspections, a reactor coming under safeguards for the first time, and failed surveillance are prime examples. Several years ago, Los Alamos developed the fork detector⁶⁵⁻⁶⁷ for the IAEA and EURATOM. This detector, together with the gamma ray and neutron detector (GRAND) electronics package, is used routinely by inspectors of both agencies to verify light-water-reactor (LWR) spent fuels. Both the fork detector and the GRAND electronics technologies have been transferred and are now commercially available. Recent incidents in the world indicate that research reactor fuel is potentially a greater concern for proliferation than LWR fuels. A device similar to the fork/GRAND combination needs to be developed to verify research-reactor spent fuels because the signals from LWR spent fuel are quite different than those from research reactor fuels.

There are two dominant types of research reactors. The first is the material testing reactor (MTR). In the US, MTR fuel is made from uranium-aluminum alloy with aluminum cladding; the uranium enrichment ranges from 20% to 93%. The fuel plates are shaped like venetian blind blades and welded into an assembly. Because of the relatively high enrichment, water is used as moderator, and the burnup can be as high as ~30%. MTR reactors designed by other countries use fuels of the same material but different geometrical configuration. The second research reactor type uses natural or slightly enriched uranium metal fuel. The cladding can be aluminum or magnesium (MAGNOX). The moderator is either graphite or heavy water. The burnup of this fuel, because of the natural enrichment, can only reach ~1200 MWd/tU.

a. Signature. The passive signals from these spent fuels can be gamma rays or neutrons and can be used to determine the burnup. The gamma-ray signal is produced primarily by the fission products. The fission products normally observed in spent fuel, after a few months of cooling, are ⁹⁵Zr, ⁹⁵Nb, ¹⁰⁶Ru-Rh, ¹³⁴Cs, ¹³⁷Cs, ¹⁴⁴Ce-Pr, and ¹⁵⁴Eu. Cesium-137 and the ¹³⁴Cs/¹³⁷Cs ratios have been shown to be proportional to burnup. The neutron output of irradiated fuel comes from the even isotopes of plutonium and to a greater degree, depending on the burnup and initial enrichment, from ²⁴²Cm and ²⁴⁴Cm.

The fissile content of these fuels can be determined by active interrogation, and because the inherent neutron

signature of the spent fuels is, in general, an order of magnitude less than that from LWR fuels, the interrogation system need not be complicated. Active interrogation has the advantage that it determines the fissile content directly, rather than using an indirect indicator such as burnup. In addition, calibration for active interrogation is relatively simple; an unirradiated fuel with a good pedigree can be used.

b. Gamma-Ray Detection. Gamma rays from the fission-product isotopes have energies ranging from 600 keV to 2200 keV. The main isotopes of interest are ¹³⁴Cs and ¹³⁷Cs, which can be used to determine the burnup. Other fission product isotopes, if they can be measured, can be used to determine the cooling time.

For gamma-ray spectroscopy, the best energy resolution is achieved using a high-purity germanium detector. However, germanium detectors require cooling to liquid-nitrogen temperatures, which makes the system impractical to use in spent-fuel applications. We have investigated other room temperature detectors: HgI₂, CdTe, and more recently, CdZnTe. The spectral performances of these detectors have been improved by two recent developments. The main reason for the poor performance is the poor collection efficiency for holes because of intrinsically low hole mobilities and the presence of high concentrations of hole trapping defects. Lawrence Berkeley Laboratory²⁹ has developed coplanar electrodes to closely emulate Frisch grids to preferentially collect single-polarity charge carriers. This has greatly improved the capability of the CdZnTe detector to measure high-energy photons and has reduced the Compton continuum. The other development is the cooling of the CdTe detector by means of Peltier cooling and pulse-rise-time-discrimination electronics.* The Peltier cooling is sufficient to cool the detector to -40 to -50°C. The temperature reduces the dark current so that it contributes only slightly to the energy resolution. At the present time, the cooled detector has sufficient resolution to determine the ¹³⁷Cs, ¹³⁴Cs, and ¹⁴⁴Pr gamma-ray peaks and can be used to determine both burnup and cooling time.

c. Neutron Detection. To measure neutrons from highly enriched or low-burnup research reactor spent fuel, a relatively high detection efficiency is needed because of the low emission rate. It is desirable to use ³He detectors in place of the standard ²³⁵U fission chambers because the ³He detector efficiency is approximately 30 times greater than that of a fission chamber. However, ³He tubes cannot operate in the high-gamma fields associated with spent fuel.

*Radiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, MA 02112.

Traditional ^3He tubes were limited to gamma fields in the range of 1-10 R/h unless massive shielding was used. We are developing ^3He gas mixtures (in cooperation with Reuter-Stokes) and preamplifiers to extend the ^3He tube operating range out to ~ 500 R/h. This should make it possible to measure the neutron emission from low-burnup reactor fuel with more efficient and portable detector systems.

2. Conceptual Design. After studying the gamma-ray detector and neutron detector, we have arrived at a conceptual design of a new fork detector. The fork detector can be installed in a spent-fuel cooling pool. The existing GRAND electronics for the LWR fork can be used. The new design is intended to be used for both MTR and MAGNOX research reactor spent fuel.

a. MTR-Type Spent Fuel. For MTR-type fuel, the initial fuel is HEU or 20% to 93% ^{235}U and the spent fuel contains very little plutonium. The primary safeguards issue is to verify that the ^{235}U has not been diverted.

To verify the ^{235}U directly, active neutron interrogation techniques are needed. We are evaluating a portable version of a new active-neutron technique that uses low-energy interrogation from an AmLi neutron source. Figure 36 shows a conceptual diagram of a fork-type detector head where the fission chambers of the original fork detector have been replaced by ^3He tubes for higher efficiency. An AmLi neutron source has been added to the base of the fork to induce fissions in the MTR fuel element. The induced fission neutrons are distinguished from the interrogation neutrons using either coincidence counting, similar to the neutron collar, or a differential transmission method.

The differential transmission method uses the higher energy (an average of about 1.5 MeV) of the induced fission neutrons compared with the lower energy (an average of about 0.3 keV) of the AmLi neutrons. The further the ^3He detectors are from the sample, the higher the signal/background ratio in the fork because the high-energy neutrons have less attenuation in water than the low-energy AmLi neutrons.

The ion chambers are used to detect gross gamma radiation. They can be used to determine rapidly the burnup profile of the assembly. Either the CdZnTe or the CdTe detector can be used to determine the burnup from the $^{134}\text{Cs}/^{137}\text{Cs}$ ratio and the cooling time from the $^{144}\text{Pr}/^{137}\text{Cs}$ ratio.

MTR spent fuel with different geometries can be assayed with this fork. A different fuel-holding attachment can be added to accommodate a different geometry of spent fuel.

The active-neutron interrogation can be calibrated using a fresh fuel with good pedigree. The calibration for the gross gamma and $^{134}\text{Cs}/^{137}\text{Cs}$ ratio is much more difficult; in most cases it is a relative measurement and provides a consistency check between measured signal and declared burnup.

b. MAGNOX Spent Fuel. MAGNOX-type spent fuel has an initial loading of natural uranium and a low total burnup. Thus, the primary source of passive-neutron emission is ^{240}Pu , and the passive-neutron count can be used to verify the plutonium directly. However, because of the low neutron emission rates, higher-efficiency neutron detectors are needed. Helium-3 detectors are used in place of the standard ^{235}U fission chambers because the ^3He detector efficiency is approximately 30 times larger

Fig. 36. Portable spent-fuel assay system interrogating an MTR spent fuel assembly.

than that of a fission chamber. One cm of lead shielding is provided in this design, which will reduce the gamma-ray dosage at 700 keV by a factor of three.

Figure 37 shows a diagram of a fork-type detector head where the AmLi neutron source has been removed because the fissile content of these fuels is relatively low and the primary source of neutron emission is ^{240}Pu . If we just place the MAGNOX fuel at the same location as the MTR fuel, the neutrons may be over-moderated; a steel can has been added to displace water and to position the fuel.

The passive neutron counting of the system can be calibrated with mixed oxide (MOX) fuel pins with good information on the fissile contents. The neutron emission for the low-burnup fuel is dominated by the plutonium isotopes with a relatively small contribution from ^{244}Cm . To determine the plutonium content of the fuel, it is important to correct for the curium, which requires calculating the ^{244}Cm buildup as a function of burnup.

This fork can be used to determine the fissile content of MTR spent fuel or the plutonium content of MAGNOX fuel. It can also be used to determine the burnup of the spent fuels. This fork complements the older fork detector designed for LWR spent-fuel assemblies.

B. Intrinsic Densitometry—In-Plant Evaluation (K. Nishida, A. Kurosawa, J. Masui, Power Reactor & Nuclear Fuel Development Corporation (PNC); and S.-T. Hsue, NIS-5)

1. Introduction. A measurement of the plutonium concentration in a sample is always necessary for

nuclear materials control and accounting. This report describes in-plant experiments with the intrinsic densitometry (ID) method of determining plutonium concentration (and isotopic distribution) that requires *no* external radioactive sources or x-ray generators but relies only on natural radiation. We carried out this project under the cooperative agreement between the PNC and the DOE in research and development concerning MC&A for safeguards. The measurements were carried out at the Tokai Reprocessing Plant (TRP) at Tokai, Japan.

The principle of ID is based on the fact that the K-absorption edge for plutonium is at 121.8 keV. If we select one peak from the plutonium spectrum on each side of the edge, the two peaks will undergo different amounts of attenuation through the solution.⁶⁸⁻⁷⁰ The dependence can be described in functional form if the far-field approximation can be applied. For a narrow concentration range, the plutonium concentration is a linear function of the ratio of peak areas.

Our experiments were divided into two parts. In the first part of the experiment, the plutonium solutions were contained in quartz cells; in the second part of the experiment, the plutonium solution was contained in stainless steel pipes.

2. Experimental Setup—Part 1. For the first part of the experiment, the plutonium solutions were in quartz cells inside a glove box; the cell was placed in a lead shield to reduce the background radiation. Gamma

Fig. 37. Portable spent-fuel assay system assaying a MAGNOX spent fuel element.

rays from the solution were collimated by a lead collimator 3 cm long with a hole 1 cm in diameter. The experimental setup is shown in Fig. 38.

Plutonium Concentration and Peak Ratio. Three different concentrations of high-burnup plutonium solutions were prepared with concentrations ranging from 100 to 208 g/L. The concentrations were determined by titration, which in general has a precision of 0.1%. Two batches of plutonium with different isotopic mixes were prepared. The isotopic distributions are shown in Table VI.

Figure 39 shows the plutonium concentration as a function of the 111/148-keV peak ratios, corrected by the isotopic factor. The data from sample B are also shown in Fig. 39. The concentrations plotted as a function of the corrected ratios can be fitted with a straight line; the correlation factor was 0.99. The data from sample B agreed with the results from sample A to within 1%. This indicates that the ID method can be used to determine the plutonium concentration, and that this method can be applied to solutions having different isotopic distributions.

3. Experimental Setup—Part 2. In the second part of the experiment, we investigated the application of the ID technique to the measurement of plutonium concentration in stainless steel pipes. The experimental setup with the pipe is similar to the first experiment except that the plutonium is contained in stainless steel pipes. The pipe is 29.9 mm in diameter, has a 2.3-mm-thick wall, and is 50 mm high. The size of the pipe is the same as that used at the main plant at which this in-plant equipment could be installed. The collimator hole diameter is 5 mm and its length is 10 mm. The front of the collimator and the inside of the hole were lined with 1-mm-thick cadmium. The assay time was 3600 s.

Plutonium Concentration Versus Peak Ratio. The concentrations of plutonium used in this part of the experiment were 128, 149, and 174 g/L. The plutonium concentrations as a function of the 111/148 peak ratios are shown in Fig. 40. The variation of the ratio is less than that of the previous experiment because in a cylindrical pipe, part of the plutonium solution near the edge of the pipe will produce little attenuation and thus does not contribute to the concentration determination.

Fig. 38. Experimental setup for the ID measurement. The quartz cells were placed in lead shields inside a glove box.

TABLE VI. Isotopic Distribution of Plutonium Samples

	Sample A (wt%)		Sample B (wt%)	
	MGA2 ⁷¹	Mass spec.	MGA2	Mass spec.
²³⁸ Pu	1.2	1.1	1.3	1.3
²³⁹ Pu	62.2	62.7	58.0	57.0
²⁴⁰ Pu	24.3	23.8	26.4	27.8
²⁴¹ Pu	9.2	9.0	10.1	10.5
²⁴² Pu	3.1	3.7	4.2	3.4

We repeated the measurement of one of the samples using another detector that is equipped for high-rate counting. The data shown in Table VII were collected for 3600 s at 9500 cps. For the high-counting-rate measurement, the precision of the peak ratio from repeated runs is 0.34%. The precision of the plutonium concentration determination is, therefore, 1.7%. The count rate can be increased by a factor of 2, reducing the precision to 1.2% for a 1-h measurement.

In summary, we evaluated the potential application of the ID technique for process monitoring in a plant environment. We found that the method can determine the plutonium concentration from 100 g/L to 200 g/L to 1-2% for plutonium solution in quartz cells or in stainless steel pipes. We also found that nitric acid concentration and the impurity level of uranium in the product plutonium solution does not affect the concentration measurement.

C. Prototype Development of Isotopic Dilution Gamma-Ray Spectrometry (T. K. Li, Jo Ann Painter, NIS-5; Tom Kelley, C-6)

Isotope dilution mass spectrometry (IDMS) has long been the most accepted technique for determining the plutonium content of input spent-fuel dissolver solutions in reprocessing plants. However, IDMS is time consuming,

Fig. 39. Plutonium concentration as a function of the measured 111-keV/148-keV ratios after the isotopic correction. Plutonium solutions were in quartz cells. Sample A and sample B had different isotopic distributions

requiring long times for sample preparation and high costs for equipment and operation. To avoid IDMS's disadvantages, but yet deliver acceptable measurement accuracy and precision, we have developed isotopic dilution gamma-ray spectrometry (IDGS) to simultaneously measure the plutonium concentration and isotopic composition of highly radioactive spent-fuel dissolver solutions. The method is similar to IDMS except that the isotopic distribution of both unspiked (unknown dissolver solution) and spiked (by adding to the dissolver solution a spike of well-characterized plutonium) samples are measured by high-resolution gamma-ray spectrometry rather than mass spectrometry, and sample preparation is simpler. The IDGS system consists of an HPGe planar detector and associated electronics, an ORTEC multichannel buffer, and an IBM-compatible PC. The computer provides the user interface, controls the multichannel buffer hardware to acquire spectral data for measurement information, automates the analysis of these measurements, and stores gamma-ray spectra on disk for

future analysis. A PC with at least a 486 coprocessor running at 33 Mhz with 4 Mb of RAM and a 120-Mb hard disk is needed.

Los Alamos staff began developing the IDGS analysis software for simultaneous measurements of plutonium concentration and isotopics in input dissolver solutions at a reprocessing plant in March 1994. The IDGS software package is a Windows program. The operating system used on the PC is Microsoft Windows 3.1, which runs on top of DOS 6.3. The Microsoft Visual C/C++ 1.0 compiler, the XVT windows, the db-VISTA Database Manager, the Ortec DLL (dynamic link library), and the libraries developed by the software section in the Los Alamos Safeguards Assay group are being used as primary development tools. Although a C++ compiler is being used, the IDGS software is being written in regular C. The XVT is a commercial GUI generator. The db-VISTA Database Manager from Raima Corporation is used to store and retrieve the parameters needed for spectral analysis.

Fig. 40. Plutonium concentration as a function of the measured 111/148 peak ratios. Plutonium solutions were in stainless steel pipes.

TABLE VII. Peak Areas and Ratios With a High-Count-Rate Detector Measuring at an Input Rate of 9500 cps.

Run Number	111 keV Area	148 keV Area	111/148 Peak Ratio
1	816920	601960	1.357
2	811487	600780	1.351
3	809363	600405	1.348
4	811623	603248	1.345
5	808622	602851	1.341
6	812033	600751	1.352
7	810725	603277	1.344
8	812032	602998	1.347
9	811565	602737	1.346
10	814141	602413	1.351
Average	811851	602142	1.348
St. Dev.	2337	1106	0.005
RSD%	0.29	0.18	0.34

The IDGS software became a complete package when a version of PCFRAM was modified to fit the IDGS requirements and the ability to take live measurements was added. The measurement option includes automatically analyzing the spectrum after a real-time measurement. Software staff worked closely with physics staff to determine more accurately the appropriate values of the analysis parameters based on a typical IDGS gamma-ray spectrum and to determine how the PCFRAM analysis may be modified to meet analysis requirements for IDGS.

The development of the integrated IDGS hardware/software package is underway. The integrated IDGS package will be tested in the next quarter.

D. Upgrade of the Dounreay Shuffler (P. M. Rinard, C. M. Schneider, and S. C. Bourret, NIS-5)

We installed a shuffler in the Dounreay (Scotland) reprocessing plant in 1984 to assay containers of leached hulls and centrifuge parts.⁷² It has been successfully operating since that date, but key components of the shuffler are aging, and it would be difficult, perhaps impossible, to replace them should they fail. Dounreay has funded (on a "work-for-others" basis) an upgrade of the shuffler to modern standards; a new electromechanical system (computer, software, stepping motor, and associated peripherals) has been completed and has passed its acceptance test.

The equipment has been delivered, but cannot be installed until there is a pause in the process line and some nearby (but unrelated) equipment is repaired. Installation is expected in 1995.

E. Safeguards Information Management Systems (SIMS) (R. Whiteson and J. E. Doak, NIS-7)

The objective of the SIMS initiative is to provide technical support on a prioritized basis to current and anticipated IAEA information management needs. This effort is aimed at enhancing the efficiency of international safeguards and strengthening their effectiveness.

The IAEA currently deals with information from multiple sources, as shown in Fig. 41. In FY 1994, we focussed on helping Joe Nardi's group in the Open Source Collection and Retrieval task of the 93+2 program. The following are some of the tasks we carried out as part of this activity.

- The Users Requirements Group of the SIMS project visited Vienna several times to gain further insight into the information management needs of the IAEA. Several new tasks with short-term goals were identified, including a task on the use of open source information. We completed a User Requirements Document for the information management needs of the IAEA and wrote an INMM paper on the subject.
- We investigated the use of Mosaic as a tool for viewing both text and graphics across several platforms. As part of this investigation, we installed and tested the server software in Vienna on the action team workstation and provided on-line documentation and instruction to the system managers on its use.
- We interviewed users of open-source information outside the IAEA and examined the kinds of tools they use for browsing and analysis. We documented the results of the study for the IAEA. The report included names of additional sources of information, names of tools, and other information provided by the users.
- We built a Mosaic home page, which can be used by the IAEA and others, that contains open sources of interest to the safeguards community. The hypertext markup language (html) file that defines this home page was delivered to Joe Nardi. We also gathered some hard-copy documents on X-Mosaic and delivered them to the IAEA.
- Topic trees (for example, open-source search queries) relevant to IAEA activities were obtained and installed on the open-source group's Sun workstation.

SIMS Initiative Vision

Fig. 41. This shows the multiple information sources that may be used by IAEA analysis.

- We obtained papers on *n*-gram analysis, for possible use in text retrieval and delivered them to the IAEA.

F. Reassessment of Safeguards Parameters (E. A. Hakkila, NIS-7; M. F. Mullen, NIS/SG; and J. L. Richter, X-5)

To strengthen safeguards, the IAEA is reassessing several of the basic parameters that are used in defining and structuring approaches and inspection criteria. The objective of this study was to provide information on the technical basis for the safeguards parameters, updating information available at the time of their initial consideration. We analyzed the implications of modifying the parameters in terms of the impact that such changes might have on the effectiveness of safeguards. This study took into account new developments in safeguards concepts and approaches and developments in the nuclear fuel cycle and nuclear technology.

Significant technical improvements have been achieved since 1970 both in the isotope separation of uranium and in reprocessing spent reactor fuel to recover plutonium. Enrichment technology today is capable of producing weapons quantities of ^{235}U in a matter of months using, for example, the nozzle process as demonstrated by South Africa or the centrifuge process as applied by Pakistan. Separation of ^{235}U from natural uranium by both methods is technically less difficult than the recovery of plutonium from irradiated fuel. Detailed information on equipment designs for both processes are available in the open literature. If LEU is available as a starting material, weapons-grade uranium is even easier to obtain (approximately 80% of the separative work required to obtain 93%-enriched ^{235}U has been performed in producing 3%-enriched material). With available enrichment facilities, the time to obtain weapons-grade uranium from natural uranium or LEU is less than a year.

The conversion times for plutonium appear to be reasonable for present day plutonium-handling technology.

This applies to plutonium in spent fuel (1 to 3 months) with the present-day IAEA practice of monthly inventories for reprocessing facilities.

It has been argued that "no nation has ever considered making weapons out of plutonium from US-type reactors" (the US announced in 1977 that it had exploded a weapon from reactor-grade plutonium), and "[reactor-grade plutonium] can be made to explode, but it is of no interest as a bomb." However, from nuclear weapons design considerations, there is no incentive to treat reactor-grade plutonium differently than weapons-grade plutonium, either in terms of goal quantity or conversion time.

G. Feasibility Study of Radiation Monitoring at an Atomic Vapor Laser Isotope Separation (AVLIS) Facility (M. C. Miller, E. L. Adams, and T. K. Li, NIS-5; R. B. Strittmatter, NIS-7)

We have evaluated radiation monitoring at an AVLIS facility for international safeguards.⁷³ The goal of this activity was to identify radiation signatures and corresponding detection technologies that might be used by IAEA inspectors for verification measurements. The goal of such measurements would be to detect the production of HEU by the AVLIS plant, possibly in a go/no-go mode. We concluded that both gamma-ray and neutron measurements are possible for materials around the separator module but are of little use for the separator itself. As a result, we recommended a combination of measurements of materials going into and out of the separator. Further development, particularly of neutron techniques, will be required when, and if, the AVLIS process is actually implemented as a source of LEU.

H. Feasibility Study of Plutonium and Uranium Measurement in an Input Dissolver Solution (T. K. Li, NIS-5; O. Kitagawa, Y. Kuno, and A. Kurosawa, TRP, PNC, Tokai-Mura, Japan)

The objective of this feasibility study is to develop the IDGS technique for the simultaneous measurement of concentrations and isotopic compositions for both plutonium and uranium in highly irradiated spent-fuel dissolver solutions at a reprocessing plant. The technique under development includes both sample preparation methods and measurement and analysis methods. TRP is responsible for the sample preparation methods including the plutonium and uranium separation (from fission products) and recovery methods. Los Alamos is responsible for the development of gamma-ray measurement and analysis methods and for the development of software.

Previous experiments^{68, 74} at TRP have demonstrated the applicability of the IDGS technique for determining the plutonium concentration and isotopic compositions in dissolver solutions. The chemical separation and recovery methods for just plutonium were anion exchange and resin beads. To save both plutonium and uranium in the sample

for simultaneous measurements, a new sample preparation method has to be developed. The sample preparation method currently under development uses 30% TBP-n dodecane to separate uranium and plutonium from fission products and then uses silica resins coated by TOPO/cyclohexane to recover both uranium and plutonium. A joint IDGS feasibility measurement of plutonium and uranium in the input dissolver solution was carried out in May at TRP, Japan. More than 30 samples, including 4 unspiked and 4 spiked dissolver solutions, 2 pure uranium, and 5 U/Pu MOX solutions were prepared and measured by using 2 high-resolution gamma-ray detector systems. The weight percents of ²³⁵U in MOX solutions varied from 0.93% to 5.39%, while plutonium isotopic compositions stayed unchanged. Plutonium isotopic compositions in MOX solutions are similar to those in dissolver solutions. To determine plutonium and uranium recovery rates, two sets of pure uranium and U/Pu MOX solutions have been prepared with and without the same separation/recovery scheme as the dissolver solutions.

I. Conceptual Designs of Instruments for the NRTA System at the Rokkasho Reprocessing Plant (RRP) (T. K. Li, S. F. Klosterbuer, H. O. Menlove, M. M. Pickrell, and P. A. Russo, NIS-5)

Task 6 is part of the Japan Nuclear Fuels, Limited (JNFL)-funded project "Near-Real-Time Accounting (NRTA) as a Safeguards Measure at Rokkasho Reprocessing Plant" under a reimbursable agreement between JNFL and the US DOE. The objective of the task is to develop conceptual designs of selected NDA instruments for the NRTA system at the RRP. We started the project in April 1994 and will complete it by October 1996.

The task includes seven subtasks:

1. A holdup measurement system for the blender in the co-denitration process,
2. A holdup measurement system for calcination and reduction furnaces in the co-denitration process,
3. A MOX product canister counter,
4. A UO₃ large-drum counter,
5. IDGS for the spent-fuel dissolver solution,
6. An unattended verification system for MOX product materials, and
7. An unattended verification system for UO₃ product materials.

For each NDA instrument, Los Alamos will develop the details of the conceptual design including measurement configuration, mechanical design, electrical design, software design (for unattended verification systems), facility interface, standards and calibration design, R&D activities, and computer hardware selections for proposed systems. A summary report will be prepared to describe the results

of the above design, preliminary engineering drawings, specifications, performance estimates, and cost estimates for procurement, fabrication, and installation.

J. Time Series Methodology (T. L. Burr, NIS-7)

The DOE Office of Arms Control and Nonproliferation sponsored our efforts to assemble a test bed of several linear and nonlinear time series (both real and simulated) that could be used to compare the performances of various old and new methods of forecasting a time series. We completed a report⁷⁵ that documents the performance of the methods and serves as background material for a more advanced report prepared under the POTAS project D89. The methods reported apply to stationary series and are (1) Box-Jenkins ARMA methods (linear); (2) a non-parametric "curve-smoother" method that defines a distance measure from each data "point" to the "point" for which a forecast is desired and uses an average, weighted by the distance measure, of how the stationary series has behaved in the past to produce an estimate; (3) neural networks; (4) MARS; and (5) a "bin" method that discretizes the data to build bins similar to, say, the low, medium, and high "bins" that are used in a different way in typical implementations of fuzzy controllers. In all cases, the time series was either stationary (qualitatively determined to have no shift in mean or variance) or could be made stationary by taking first or, at most, second differences. Also, in all cases, we had to estimate the lag (the number of previous observations that affect the present observation) before building a forecasting method. Method number (2) refers to a distance measure between "points" because, for example, if the lag is 3, then a "point" is a three-dimensional point, with distance defined analogously to ordinary Euclidean distance.

The main conclusions are that moving average models must be treated differently from autoregressive models to be correct in the strictest sense, but all models can be reasonably well modeled by a two-step autoregressive model. The first step assumes that the original series follows an autoregressive model. The second step fits a second autoregressive model to the forecast errors from the first step if that is deemed necessary. This is not completely satisfactory for all models, but performs reasonably well, and allows the use of a host of methods such as methods (2)-(5) above that are best suited for autoregressive models. A follow-on study is planned in which results from methods such as (2)-(5) above will be compared to results from situations without the serial correlation that is present in nontrivial time series.

II. TECHNICAL EXCHANGES

A. Interactions with France

1. Neutron Multiplicity Measurements (K. L. Coop, C. L. Hollas, and G. Arnone, NIS-6). Two experts

from the French CEA (Commissariat à l'Energie Atomique) establishment at Cadarache visited Los Alamos in July 1994 to discuss nondestructive analysis methods for the assay of low-level radioactive waste with Los Alamos staff. The Los Alamos TGS method and the active neutron assay method using thermal and epithermal interrogating neutrons (CTEN) were discussed in detail. Passive neutron multiplicity measurements and the subsequent analysis also were discussed.

Two Los Alamos staff members visited the Cadarache facility in September 1994 for experiments performed on the PROMETHEE V active neutron assay instrument, which has many attributes similar to the Los Alamos CTEN instrument. Specialized electronic modules developed at Los Alamos to be used with the CTEN instrument were incorporated into the PROMETHEE V system. The Cadarache method of measuring neutron multiplicities resulting from the fissions induced by the neutrons from the PROMETHEE V neutron generator was examined. Similar neutron multiplicity measurements are to be included in the CTEN instrument in FY 1995.

One or more French personnel from Cadarache are expected to visit Los Alamos in FY 1995 to work with the CTEN project.

2. Spent Fuel (P. M. Rinard, G. E. Bosler, and H. O. Menlove, NIS-5). Technical exchanges on safeguarding spent-fuel assemblies and products continued under a US DOE-French CEA agreement. Three safeguards topics were involved.

The plutonium product from a reprocessing plant is of course already under safeguards, and assay techniques exist. Waste streams normally contain insignificant amounts of fissile materials, but as reprocessing plants grow in capacity, the waste streams become more important. The waste streams also contain other isotopes that are intense emitters of neutrons and gamma rays, greatly complicating the problem. Some concepts for assaying waste streams are of mutual interest and were discussed; future collaborative efforts are likely.

Burnup codes are routinely used to aid with the assays of spent fuel assemblies, so it is important to have confidence in the codes. Personal computers are now widely used for such purposes, so the burnup codes make some compromises to accommodate the computers' limitations. The Los Alamos CINDER-PC and the Cadarache KAFKA codes were compared on 27 different burnup situations. Some minor differences were caused by the choices for nuclear constants, but a major difference was seen in the atom densities of the curium isotopes. It is suspected that different neutron cross sections were used, but the issue has not yet been resolved.

Techniques for improving the accuracy of assays with ²⁵²Cf shufflers were discussed. The Los Alamos case arises with 55-gal. drums containing moderating matrices; the Cadarache interest is in a 200-gal. drum of leached hulls that does not rotate during irradiation by a ²⁵²Cf source. In

both cases, the measured count rate varies with the position of the fissile material within the drum. Medium-resolution imaging techniques have been studied at both laboratories to help with this problem. Some test data with the Cadarache drum are being used with two of the techniques (image reconstruction with the SIMPLEX method, and neural networks) to compare their relative merits.

B. Interactions with the Former Soviet Union

1. **Russian National MC&A (H. A. Smith, NIS-5; E. A. Hakkila, K. E. Thomas, T. L. Burr, and E. A. Kern, NIS-7).** Part of the US nonproliferation effort involves collaborations with members of the nuclear programs in Russia on the subjects of MC&A and the physical protection (PP) of nuclear material, with the goal of improving nuclear material safeguards throughout the former Soviet Union. In September 1993, a government-to-government implementing agreement was signed that addresses the US assistance to Russia on MC&A, PP, and regulatory questions. The assistance will take the form of US technical support for the enhancement of the MC&A and PP systems at a Russian model facility, with extension to other facilities considered in the future. Initial efforts will focus on non-sensitive nuclear materials (that is, LEU), with possible extension of activity to materials of higher safeguards interest in the future, as US-Russian working relationships grow and tangible results are obtained with LEU safeguards. In February of 1994, Los Alamos participated in the first US/Russian Technical Working Group (TWG) in Moscow to select the model facilities for the initial assistance under this implementing agreement. The facility selected was the LEU fuel-fabrication operation at the Elektrostal Machine Building Plant near Moscow. Los Alamos is taking the lead in MC&A, and SNLA is leading the PP assistance. The US NRC has the responsibility for assistance in developing a regulatory structure for Russian national nuclear safeguards.

In June 1994, a US team (with Los Alamos participation) conducted a site visit to Elektrostal to assess the present level of MC&A and PP activities and to identify specific projects and schedules for US assistance in enhancing those efforts. Projects were identified for completion in the near-term (approximately December 1994), mid-term (approximately June 1995), and long-term (approximately December 1995). Los Alamos concluded FY 1994 with a major near-term activity of hosting six Elektrostal personnel at the Siemens LEU fuel-fabrication facility in Richland, Washington, for a week. During this visit, the Russians were given introductory training on US MC&A systems for LEU, accompanied by in-depth tours of the Siemens facility to illustrate the concepts. The remaining projects, to be completed during FY 1995 and FY 1996, involve several MC&A and NDA training courses, procurement of

MC&A measurement equipment, and assistance in developing an automated, computer-based MC&A capability at the Elektrostal facility.

2. **Ukrainian National MPC&A System (G. A. Sheppard, NIS-5; E. A. Hakkila, NIS-7).** On December 18, 1993, the US and Ukraine signed a joint agreement to facilitate safe and secure nuclear material physical protection, control, and accounting (MPC&A) in Ukraine to assist in the prevention of nuclear weapons proliferation. The two nations agreed to collaborate on enhancing the Ukrainian national MPC&A system through technical support, equipment installation, and training at designated facilities.

Los Alamos staff are participating in the development of a program plan to implement the MPC&A agreement. The program tasks include the following:

- conducting TWG meetings and facility visits to scope out the elements of the MPC&A systems to be enhanced;
- improving and implementing MPC&A systems at model facilities;
- supporting these systems through instrumentation and training programs; and
- conducting ancillary activities, such as the fabrication of NDA standards (in Ukraine) and developing a comprehensive glossary of MPC&A terms used in regulations, training, and operations.

In March, the first joint US-Ukrainian working group convened in Kiev to conduct preliminary discussions on enhancing the Ukrainian MPC&A system. In June, a second working group convened in Washington, DC, to establish specific details, such as the selection of the model facilities at which pilot efforts to enhance the Ukrainian MPC&A system will be made, the transfer of facility information needed to begin design activities, and the determination of the content of the relevant training needed to support operation of the system. The Ukrainians designated a research reactor at the Kiev Institute for Nuclear Research and the South Ukrainian Nuclear Power Plant as model facilities. In September, site surveys were made by US teams to both model facilities.

3. **Kazakhstan (E. A. Hakkila, T. L. Burr, and B. Erkkila, NIS-7; J. K. Sprinkle, and G. E. Bosler, NIS-5).** The US and Kazakhstan have signed an agreement to improve materials control and accounting and physical protection at Kazakh nuclear facilities. Assistance from the US, the UK, Sweden, and Japan is coordinated by the IAEA. US assistance is supported by the DOE and through the Nunn-Lugar Threat Reduction program of the Department of Defense.

A Los Alamos staff member participated in a joint IAEA, US, Sweden, and Japan meeting to tour Kazakh nuclear facilities to assess safeguards needs and areas of assistance from the various donor countries. Facilities toured included the Ulba LEU fuel fabrication plant at Ust Kamenogorsk, the BN-250 breeder reactor at Aktau, and a research reactor at the Institute of Nuclear Physics in Almaty.

Under the Nunn-Lugar program, a TWG meeting between US and Kazakhstan officials was held in Almaty and Ust Kamenogorsk in July. The visit to Ust Kamenogorsk included a tour of the LEU fuel pellet manufacturing process. The MC&A system being provided to the facility by Sweden was identified. Two Los Alamos safeguards experts visited the Ulba plant in early August to observe a Swedish training exercise on their facility-level computerized MC&A system and to deliver a PMCA with a sodium iodide detector to the facility. Some training on the use of the PMCA also was provided.

Under the Nunn-Lugar program, a training course on the Fundamentals of Nuclear Materials Accounting was prepared with emphasis on the Ulba plant. The course was presented in September. During the training course, staff members advised facility personnel on establishing a material structure for the facility. One member of the staff remained at the facility to provide additional training on the use of the PMCA and to assist in performing holdup measurements.

From information about the Ulba plant obtained during three previous visits to the facility, a Los Alamos staff member prepared a summary document describing the facility. The document was distributed to members of the US site survey team who visited the facility in late September.

III. NUCLEAR NONPROLIFERATION ACT TRAINING (G. E. Bosler, J. Sander, NIS-5; E. A. Hakkila, NIS-7)

The US DOE, the DoS, and the IAEA sponsor a biennial course on States Systems of Accounting for and Control of Nuclear Material (SSAC). The next SSAC course is scheduled to be held in Santa Fe and Los Alamos, New Mexico, and Hematite, Missouri, April 19 to May 5, 1995. The Memorandum of Understanding for the course has been prepared and submitted to the DOE and DoS for transmittal to the IAEA. The course syllabus has been finalized and letters of invitation to speakers were prepared for the DOE. Arrangements for the course, including hotel contracts and a contract with ABB Combustion Engineering to host the course during the last week in Hematite, have been finalized. Letters of invitation have been sent by the IAEA to member states to submit names of prospective participants.

Part 3. Related Safeguards Projects

PART 3. RELATED SAFEGUARDS PROJECTS

I. SUPPORT TO THE DOE COMPLEX

A. Savannah River/NucMASloe (W. J. Whitty, NIS-7)

The Safeguards Systems Group's MAWST⁷⁶ computer program, which calculates material balances, the amount of material in inventory, variances, and the decomposition of the total variance into contributions from measurement components, is being added to the WSRC's generic, computerized accountability system, NucMAS. The addition fulfills DOE Order 5633.3B⁷⁷ requiring that inventory difference control limits be based on variance propagation (or another statistically valid technique). This software application, called NucMASloe, is a layered product for NucMAS.

We shipped a Beta version of NucMASloe to WSRC for testing. Previous implementations had been shipped earlier in the year for demonstration. Two development meetings were held at SRS and one at Los Alamos to resolve some questions on the use of NucMASloe, to deliver some revised design documents, and to resolve some implementation issues. Some of the original requirements and subsequent design agreements were eliminated because they were no longer necessary; they were to handle special conditions for a facility that will never operate, or they were made unnecessary because design changes provided simpler means to achieve the same results. Other requirements and design agreements were postponed until there has been some experience using NucMASloe and because WSRC requested changes in the MAWST code that will affect NucMASloe. The modifications have been completed, tested, and documented. The current plan is to demonstrate the full use of NucMAS and NucMASloe for a materials balance area and to include the variance propagation design and modified software in LANMAS (See Part 1, Sec. I.G.1).

We expect WSRC to test the software in the near future. Design documentation is being revised to reflect the changes in the design, including data flow diagrams, entity-relationship diagrams, program structure diagrams, and forms documentation using the DEFT (DEFT is a trademark of DEFT, Inc.)* software engineering tool. The revision of the design is approximately 90% complete. The users manual also is being revised.

B. Holdup Measurement Uncertainty at the Rocky Flats Environmental Technology Site (G. A. Sheppard, NIS-5)

Procedures established at the Rocky Flats Environmental Technology Site to measure nuclear material holdup

require that ducts be measured at contact. The advantages of measuring the ducts at contact using well-collimated detectors are improved signal-to-background ratios and fixed detector-to-duct geometries. However, contact or near-contact measurements of nuclear material holdup are especially sensitive to the unseen configuration of the deposit within the duct. To achieve an accurate assay, the deposit geometry must be correctly deduced and accounted for during the data analysis. This is because the detector is not sufficiently distant to neglect the deposit dimensions and validate the assumption that the deposit approximates a line, as in the generalized geometry approach.⁷⁸⁻⁸⁰ Estimating holdup based on a deposit assumption that is inconsistent with the actual deposit geometry can contribute more to measurement bias than any other uncertainty term.

The technique used by EG&G personnel involves taking measurements in pairs, with the detector viewing the holdup deposit at contact from above and below a horizontal duct. The analysis method is based on one of two deposit geometry assumptions, depending on the duct orientation and the ratio of the top and bottom net region-of-interest count rates. If the duct is vertically oriented, the deposit is assumed to be annular. Deposits in horizontal ducts are also assumed to be annular if the top-to-bottom count rate ratio is not determined with 95% confidence to be less than unity. When the ratio is less than unity, the "width" model is applied.⁸¹ This model assumes that the deposit is a ribbon of uniform thickness lying along the bottom of the duct, that its length exceeds the top detector's field of view, and that its width (transverse to the duct axis) is less than the top detector's field of view but greater than that of the bottom detector.

Process experience and extensive inspections with remote video cameras indicate that one of these two models (annular or width) is a valid description of the deposit geometry in the majority of duct measurement locations. However, there are a few feasible deposit geometries to which neither model applies. In these cases, either the width or annular model will be applied, based on the top-to-bottom count-rate ratio. The result will be biased at that measurement location. The Safeguards Measurements group at Rocky Flats asked for our assistance in quantifying the biases that result when deposit geometries are not consistent with either the width or the annular model. To do so we performed a series of Gedanken experiments. Table VIII illustrates the geometries tested and the range of biases that resulted.

The results of our study indicate that the bias introduced by incorrect deposit assumptions is manageable, as long as there remains reasonable confidence that the vast majority of the deposit geometries encountered in ducts at Rocky Flats can be described by either the width or the annular model. Primarily, such bias would occur when poor counting statistics are obtained and would be caused by applying the annular model when the width model is the correct one. Typically, the consequence is an overestimate of the nuclear material held up in clean or remediated ducts.

*DEFT, 557 Dixon Rd., Suite 111, Toronto, Ontario, Canada M9W 1H7.

TABLE VIII. Modeled Deposit Geometries				
CASE	Count Ratio (R)	Applied Model	Bias (%)	
			10" Duct	20" Duct
R<1	Width	0%	0%
R=1	Annular	0%	0%
R=1	Annular	-47 to +81%	-49 to +101%
R<1	Width	-85 to -68%	-86 to -70%
R=1	Annular	-47 to +81%	-49 to +101%
R<1	Width	-20%	-20%

C. Savannah River Uranium Solidification Facility (USF) (G. A. Sheppard, C. W. Bjork, E. Adams, C. M. Schneider, E. C. Horley, L. L. Pollat, P. J. Polk, G. Walton, D. C. Garcia, H. R. Dye, J. G. McDow, G. G. Ortiz, R. S. Biddle, S. C. Bourret, B. S. Cordova, F. A. Duran, and A. M. Romero, NIS-5)

We fabricated, assembled, and tested a combined neutron/gamma-ray waste drum assay system for the planned USF at the SRS's H-area. The system consists of a pass-through shuffler and a second-generation SGS built by Atlan-Tech, Inc., under a competitive technology-transfer procurement. We equipped it with the latest generation of SGS software, which now includes the capability to set regions of interest for up to 20 gamma rays. With judicious selection of the gamma rays on which the assay is based, up to 20 isotopes can be measured simultaneously. The shuffler was designed for installation in the MAA boundary to assay waste drums and assure against diversion of SNM quantities above the discard limit. Both instruments were intended to combine neutrons and gamma rays to assay waste for plutonium, uranium, and other nuclear materials encountered in the USF.

Acceptance testing was rigorous, requiring a 100-hour test of the equipment in continuous operation. The main acceptance test was held in January, and elements of

the test were repeated in March to eliminate several problems that were encountered in January. There were problems with the commercial power supply used to control the doors to the shuffler assay chamber, and this equipment was replaced. On the SGS, mechanical problems with the transmission source shutter and the drum turn-table necessitated redesign or replacement or both of some components.

The system was disassembled and shipped to Savannah River in May. The USF schedule is now on hold, and the shuffler and SGS were placed in storage until the decision was made to return them to Los Alamos to be retrofitted for use in the inventory verification program at SRS's Building 235-F.

D. SGS/Isotopic Integrated System Project (G. A. Sheppard and T. E. Sampson, NIS-5, and T. A. Kelley, CIC-12)

When the USF was suspended at the SRS, we had to change our plans to implement an integrated SGS/Isotopics system there. Our original plan had been to integrate gamma-ray isotopics measurement into a MicroVAX-based SGS that was intended for the USF. Measurements were to be a collaborative effort between WSRC staff and Los Alamos staff after installation. We have identified another facility with which to collaborate on measurements using integrated SGS/isotopics software and are developing a MS-Windows-based system that we plan to deliver to the Los Alamos Nuclear Materials Measurement and Accountability group in FY 1995. We will collaborate with them to test the system and to make measurements at the LAPF.

E. Hybrid Segmented/Tomographic Gamma Scanner (G. A. Sheppard, T. H. Prettyman, and G. Walton, NIS-5; R. J. Estep, NIS-6)

We are developing a hybrid gamma-ray scanner capable of assaying a wide range of sample types using a variety of scanning protocols. Scanning protocols will include the following: far-field scanning, segmented gamma-ray scanning, tomographic gamma-ray scanning, and user-defined scanning protocols. The hybrid scanner will be able to assay samples ranging in size from 1-ft x 1-ft x 2-ft boxes to 83-gal. overpacks.

Central to hybrid scanning is a variable-geometry aperture that will replace the fixed aperture currently in place on the prototype TGS. The aperture will consist of pairs of overlapping tungsten plates that can be automatically or manually adjusted to match the selected scanning protocol. For tomographic scans, aspect ratios of more than 10:1 can be achieved without significant shine-through for gamma-ray energies up to 2 MeV. For segmented gamma-ray scans, the field of view can be enlarged to examine axial segments of 83-gal. overpacks.

The conceptual design, detailed technical specification, and mechanical design package have been completed.

The first variable geometry collimator will be constructed and installed on the prototype TGS in FY 1995.

The purpose of the hybrid scanner is to enable high-throughput assays of waste streams containing a wide range of matrix densities. For low-density waste ($<0.2 \text{ g/cm}^3$), segmented gamma-ray or far-field assays can be performed with acceptable accuracy. In this mode, throughput of the scanner is high. For TRU waste streams, twenty-four 55-gal. drums can be assayed in an 8-hour shift (approximately 20 minutes per drum). For medium and high-density waste ($>0.2 \text{ g/cm}^3$) tomographic gamma-ray scanning can correct for heterogeneity effects. In the TGS mode, 8-10 drums can be assayed per shift.

Because diagnostics from far-field or segmented gamma-ray scanning can be used to flag heterogeneity effects in large samples, hybrid scanning can be used to achieve high throughput without sacrificing accuracy. Drum weight, the results of real-time radiography, and segmented gamma-ray scanning diagnostics can be combined to estimate the severity of heterogeneity effects. When heterogeneity is detected, accuracy can be improved by switching to the tomographic mode.

We are developing diagnostic techniques using data from TGS and SGS scans of 32 TRU waste drums and hundreds of waste drum mock-ups. The 32 TRU drums were selected from the Los Alamos TRU waste storage facility and had densities ranging from 0.15 to 0.5 g/cm^3 , and plutonium inventories ranging from 1 to 165 grams of ^{239}Pu .

II. ARMS CONTROL AND NONPROLIFERATION TECHNOLOGY

Detector for Fingerprinting Weapons Components (W. C. Feldman and D. Morley, NIS-1; R. C. Byrd, NIS-2; M. C. Miller, M. S. Krick, G. Walton, and S. C. Bourret, NIS-5; K. Fuller, NIS-4). Verification of nuclear weapons dismantlement activities poses many challenges, particularly in the case of radiation measurements. There are important requirements in the areas of both data content and protection; verification measurements must have enough sensitivity to be meaningful while at the same time protecting weapons design information. Clearly, traditional NDA approaches will be too revealing, and other procedures that either severely restrict or eliminate radiation measurements will have questionable meaning because of a lack of sensitivity to the object being verified. One potential solution to this problem is a multiplicity fingerprint that contains both gamma-ray and neutron information and is "scrambled" at the front end by the detection physics. We are developing such a system using detector technology developed for space applications and electronics developed for nuclear materials safeguards.

The detector that we are investigating is a combination of boron-loaded plastic⁸² (BC454) and bismuth germanate (BGO). The BC454 and BGO detectors are optically coupled (phoswiched) so that light generated during the detection process is collected by a single photomultiplier tube. This phoswich configuration provides capabilities that neither detector has alone, while serving to mix data at the front end. An array of these detectors will

be used, with their combined output being fed into a shift register that has multiplicity capability.⁸³ The resulting multiplicity distribution is characteristic of the item being measured but cannot be interpreted quantitatively. Figure 42 shows the detector array used for laboratory proof-of-principle measurements. The central sample cavity is surrounded by six BC454/BGO detectors.

The detector combination is sensitive to both neutrons and gamma rays. Fast neutrons enter the BC454, scatter and thermalize, and are finally captured by ^{10}B by means of an (n,α) reaction. The ^{10}B is intimately mixed in the plastic scintillator material, and the terminating reaction occurs with a die-away time of $\sim 2 \mu\text{s}$. The existing detector is composed of 5% boron by weight ($\sim 1\% \text{ }^{10}\text{B}$). The plastic scintillator produces light pulses from both proton recoils (fast-neutron interactions) and the (n,α) reaction with ^{10}B (thermal-neutron interactions). The detector also is sensitive to gamma radiation resulting from Compton scattering. The BGO detector is gamma-ray sensitive, having a resolution comparable to NaI. By virtue of the phoswich arrangement, the BGO also has a neutron sensitivity through the detection of the 478-keV gamma ray from the (n,α) reaction on ^{10}B in the plastic scintillator.

The components of the combined signal are listed in Table IX. The energy information is complex because of differences in light collection and in the different quantum yields of the BC454 and BGO.

The multiplicity distribution resulting from the combined detector output contains contributions from the detector as well as from the source. The detector contributes a time-correlated signal through the neutron scatter-and-capture process and through the mechanism of multiple scattering of neutrons and gamma rays. This results in a multiplicity that, while being characteristic of the item being measured, has artifacts that prevent quantitative analysis. Figure 43 shows preliminary data obtained with the six-detector array, comparing the measured multiplicity distributions for ^{60}Co (gamma-ray source), AmB (random neutron source), and ^{252}Cf (correlated neutron source). The pure gamma-ray source has no correlations, while the neutron sources do. For the reasons given above, even a random neutron source has a low multiplicity, but the distribution of events is much different than the ^{252}Cf source. The difference between a pure neutron multiplicity (thermal counter) and the combined neutron and gamma-ray multiplicity (BC454/BGO) can be illustrated by defining a figure of merit (FOM) that is proportional only to moments of the multiplicity distribution. For ^{252}Cf , where one can assume that contributions from multiplication and (α,n) are negligible, we obtain

$$FOM = \frac{ST}{D^2} = \frac{2}{3} \left[\frac{v_{s1} v_{s3}}{v_{s2}^2} \right],$$

where

S, D, T = singles, doubles, and triples rates, and

Fig. 42. Photograph of six-detector assay used for laboratory proof-of-principle measurements.

V_{s1}, V_{s2}, V_{s3} = first, second, and third reduced moments of the spontaneous fission neutron distribution.

Results of this calculation for a ^{252}Cf sample measured in a thermal counter and the BC454/BGO array are given in Table X below. We will be optimizing the detector configuration for measuring 30-gal. drums, adding a derandomizing buffer (to allow for fast coincidence detection), and analyzing the data (to determine the exact degree to which quantitative information may or may not be extracted). A demonstration of this new technology is scheduled to be held at Rocky Flats in 1995.

III. PROGRAM FOR TECHNICAL ASSISTANCE TO IAEA SAFEGUARDS (POTAS)

A. AWCC Criticality Study (M. C. Miller, NIS-5; D. D. Yearwood, ESH-6)

We have completed and documented⁸⁴ a series of calculations to estimate k_{eff} for various HEU samples inside an AWCC. Large samples (greater than 5 kg) of various material types (metal, oxide, and fluoride) were simulated under a variety of conditions (dry, moist, and with and without cadmium liner and nickel reflector). All samples, including 20 kg of metal, proved to be subcritical even under full water reflection conditions provided that the sample's moisture content was below 30% by weight. For powder samples of 10 kg or more and 30% water by weight, criticality can be achieved if the cadmium liner and nickel reflector are removed from the sample cavity.

B. Acoustic Resonance Spectroscopy (C. T. Olinger, NIS-7)

The objective of POTAS Task A.189 is to evaluate the feasibility of applying ARS to solving some problems in international safeguards. The goal is to demonstrate the feasibility of detecting changes from baseline configurations or for monitoring safeguards-related processes.

ARS can be used to measure the acoustic characteristics of process equipment. Physical parameters, such as acoustic velocity, viscosity, and density, as well as interfaces between different materials and container geometry can affect acoustic resonant characteristics that can be established inside the test item as well as phase relationships between an excitation and detection transducer. Because the acoustic resonance patterns are affected by so many variables, it may be possible to use the acoustic patterns established inside a container to monitor for undeclared

TABLE IX. Components of Detector Response

BC454	BGO
Proton recoils (fast neutron)	Gamma rays, including 478-keV γ from $^{10}\text{B}(n,\alpha)$ reaction
$^{10}\text{B}(n,\alpha)$ reaction (thermal neutron)	
Gamma rays, including 478-keV γ from $^{10}\text{B}(n,\alpha)$ reaction

Fig. 43. Comparison of AmB (random neutron source) and ²⁵²Cf (fission neutron source) shift register response. The ²⁵²Cf shows a higher multiplicity than the AmB. Although neutrons from AmB are not time correlated, a low multiplicity is evident because of the time relationship between proton recoils and capture events.

changes in the container, to perform process monitoring, or to verify declarations, such as the fill height within a container such as an accountability tank.

We have concentrated our efforts in two main areas. First, we are assessing whether acoustic signatures can be used to nondestructively and nonintrusively examine the internal plumbing of a process tank. We want to be able to detect undeclared changes in a process or accountability tank such as the addition of plumbing or a blind volume to displace process solution as might be done in a diversion scenario. Second, we are examining the use of acoustics in determining the fill level of a container or process tank.

Tests to use acoustics to monitor for plumbing changes within a process tank first centered around characterizing the baseline spectrum of the container at various frequency ranges that corresponded to anticipated acoustic modes of vibration (that is, modes representing standing

waves in the air cavity between the container walls) and at frequencies with wavelengths corresponding to the size of the internal pipes examined. Although some of these tests have shown favorable results in detecting differences in the plumbing configuration, it is unclear how well these results will translate to operational facilities.

It appears more favorable to use acoustics in verifying declared fill levels in accountability tanks. The fill height in a container can be determined with reasonably high sensitivity by establishing a standing wave of ultrasound between the inner and outer surface of a container's wall. If the transducer is moved vertically along the container, the frequency and amplitude of the standing wave changes noticeably when the height corresponds to the air/liquid interface within the container. A hand-held sensor could be made for this application, making it highly field-portable. In addition to verifying the fill height within a container, this approach can be used to detect stratification of material either for verification or for process monitoring purposes.

An additional acoustic method for monitoring fill levels involves permanently placing transducers on the tank's walls in a vertical arrangement and measuring the time delay in transmitting a tone burst from one transducer to the next. When the fluid inside the container is between two adjacent transducers, the difference in impedance introduces a time delay in transmission. If the air/liquid interface is between the sending and receiving transducer, the fill level can be easily calculated. This approach might

TABLE X. Figure of Merit Results (²⁵²Cf)

Case	FOM
Theoretical	0.56
Thermal ^a	0.59 ± 0.02
BC454/BGO (source #5115NC)	0.82
^a Average value from sources CR-4,5,6, and 7.	

be more appropriate for use by the facility operator because it requires permanently mounting the transducers, but the technique could be used to enhance facility safeguards and for process monitoring applications to minimize waste.

C. Authentication of Reprocessing Plant Safeguards Data Through Correlation Analysis (POTAS Task D89) (T. L. Burr and L. E. Wangen, NIS-7, M. F. Mullen, NIS/SG)

We completed the draft final report, incorporating minor changes suggested by a reprocessing plant expert from the IAEA. A one-week workshop was held in Vienna to decide which of the methods that were reviewed and studied in the report would be used. The conclusion was to use realistic simulated data characteristic of what can be expected from the proposed RRP in Japan, to try all candidate methods, to invite other workshop participants to help define what details would be simulated, and to experiment with their fault- or loss-detection methods.

D. Authentication of Operator Process Monitoring Systems Using Expert Systems (POTAS Task D101) (T. L. Burr and L. Stoltz, NIS-7)

We are writing software to monitor tank activities such as tank-to-tank transfers, evaporations, and acid additions that occur in reprocessing plant tanks. An expert system will identify the kind of tank activity that is occurring by simple analysis of changes in the tank levels, densities, or temperatures. This will facilitate the creation of a historical database containing the level, density, and temperature of each tank during, for example, all tank transfers. Then analysis methods will be implemented to monitor each kind of activity. The goals then become (1) to detect biases

in the level-to-volume calibrations, (2) to learn to classify all tank events as normal or non-normal, and (3) to begin to apply internal consistency checks to authenticate that an operator's process monitoring system is reporting the true state of the plant and therefore can be used for international safeguards.

IV. SUPPORT TO JAPAN

A. Conceptual Design Study of NDA Equipment for the Advanced Thermal Reactor Fuel Fabrication Line (M. C. Miller, H. O. Menlove, D. H. Beddingfield, and T. R. Wenz, NIS-5; K. Asakura, PNC)

We have completed a conceptual design study for new NDA instrumentation to be used by the IAEA inspectors at the Advanced Thermal Reactor (ATR) fuel fabrication line.⁸⁵ The ATR line will be an addition to the Plutonium Fuel Production Facility (PFPP), which currently produces fuel for the JOYO and MONJU reactors.

A fully integrated approach is envisioned whereby the NDA instrumentation and C/S equipment will be connected to a local area network. Data from all types of systems will be transmitted to a central inspection room where inspectors will be able to review and analyze without having to enter the process areas. Redundant data storage for the NDA systems will be at the instrument location and will be available in case of network failure.

Table XI lists the NDA stations with the number and type of detection equipment used. All systems except SFAS and INVS/HRGS will be operated in the continuous, unattended mode. The hardware phase of the ATR line project is expected to begin in mid-1994 and continue for a period of 3-5 years, depending on the plant construction schedule.

TABLE XI. NDA Equipment Summary			
Plant Area	NDA Equipment ^a	Number of Units	Notes
Glove Boxes	MAGB	5	Powders and Pellets
	MAGB/HRGS	3	Powders and Pellets
	GBAS	3-5	Holdup
Furnace	SFAS	2	Continuous and Batch Operations
Fuel Pin Storage	FPAS	1	Scanning Required
Fuel Assembly Storage	FAAS	1	Scanning Required
Analytical Laboratory	INVS/HRGS	1	Small Sample Analysis
^a Neutron coincidence counters—Material Accountancy Glove Box counters (MAGB) Glove Box Assay System (GBAS) Sintering Furnace Assay System (SFAS) Fuel Pin Assay System (FPAS) Fuel Assembly Assay System (FAAS) Inventory Sample Counter (INVS) Gamma-ray Isotopes—High-Resolution Gamma System (HRGS)			

B. Nuclear MC&A Measures for Safeguards at the PFPP at Tokai (D. D. Wilkey, W. J. Whitty, and J. T. Markin, NIS-7)

Under Appendix II of the specific memorandum of agreement (SMA-11), signed in September 1992, we are responsible for contributing to a joint effort with PNC in a conceptual design study of NRTA systems for the ATR fuel fabrication line. In support of this effort, we are working on a conceptual design for the interface between the advanced accountancy system of the ATR line and the NRTA computer that will run the MAWST code. This design describes the steps required to produce software for the interface. The code for the interface will be written in Japan. In addition, we delivered to PNC a draft conceptual-design report on the NRTA system for the ATR line. The latter report includes a proposal for completing the NRTA conceptual design and performing system studies of the ATR line similar to those done previously for the FBR line. This activity awaits PNC approval and funding.

C. Hybrid Densitometer for the Nuclear Fuel Cycle Safety Engineering Facility (NUCEF) (S. T. Hsue, J. K. Sprinkle Jr., R. Cole, and M. Collins, NIS-5)

This hybrid instrument combines two solution assay techniques, K absorption-edge densitometry and x-ray fluorescence (XRF), to determine the concentrations of uranium and plutonium in mixtures of the two elements in solution. It uses the strength of the two techniques—the relatively stable calibration (four to five years between calibrations) and superior precision (0.3% in a 1000-s assay) of the densitometry method and the wide dynamic range of the XRF method—to determine the uranium concentration and uranium/plutonium ratios. It has been successfully applied in Europe to assay input dissolver solutions (highly radioactive, uranium/plutonium ratio ~100) as well as the product solutions of reprocessing plants.

We have been contracted by the NUCEF of the Japanese Atomic Energy Research Institute to develop a hybrid densitometer for their facility. The design goal of the instrument for NUCEF is to assay a wide range of uranium and plutonium concentrations (10 g/L to 500 g/L) without sample preparation. In addition, the instrument will assay mixed uranium/plutonium solutions with plutonium being the dominant element; this problem has not been studied before and is a challenge because the presence of plutonium x-rays will excite the uranium x-rays making the XRF measurement more complicated than when uranium is the dominant element. The instrument is built around a square stainless steel tube that is an extension of the glove box. It consists of an x-ray generator with a heavily collimated beam. The densitometer detector, on the opposite side of the sample cell from the x-ray generator, measures the transmitted beam through the solution. The XRF detector, located 150° from the collimated beam, measures the uranium or plutonium x-rays fluoresced from the solution. A sample tray accommodating up to six solution samples moves through the beam in sequence. The tray is controlled by a Compumotor for precise positioning of the sample in

the beam. Details of the instrument were described in an earlier report.⁸⁶

The hybrid system underwent acceptance tests at Los Alamos by the NUCEF staff in July 1993. Subsequently the system was accepted by the IAEA staff in September. For the IAEA acceptance test, a set of uranium solutions was shipped to Los Alamos from Vienna. We measured each of the standards in this set at least twice; five runs each with an assay time of 1000 s. Table XII below summarizes the results of the measurements.

The measured concentration was based on the D_m ($\Delta\mu$) value of 3.3331 which was the calibration arrived at by Ottmar⁸⁷ in 1984 with a completely different hybrid system. Based on our measurement, the D_m for the 2-cm cell is 3.3241 and the D_m for the 4-cm cell is 3.3528. It seems that the densitometry calibration is independent of the system to ~1%. The small effects depend on the scattering of the gamma rays in the measurement geometry. Small differences in geometry determine angles through which the gamma ray can scatter into the detector. This is the reason that the calibration factor for the 2-cm cell is slightly different from the 4-cm cell; this is also the reason that the calibration from one hybrid system may differ slightly from another.

The densitometer hardware was installed at NUCEF and the x-ray generator tested in January 1994. A preliminary version of the software was used to test and demonstrate the instrument. The glovebox and procedures must undergo Japanese safety certification before uranium solutions can be introduced into the glovebox. The calibration for uranium is scheduled for April 1995. After preliminary work with uranium, another safety review is required before plutonium can be introduced into the glovebox. We are continuing to upgrade the densitometer software. A second installation trip will be made to deliver a software upgrade before plutonium is introduced into the system.

D. NRTA Study for the RRP (E. A. Hakila, C. A. Coulter, and T. L. Burr, NIS-7; T. K. Li, NIS-5)

The Safeguards Assay Group and the Safeguards Systems Group entered into a DOE-approved work-for-others contract with JNFL to continue a study of NRTA for the RRP. The RRP facility comprises two components: the main process area, in which irradiated reactor fuel is processed to produce plutonium nitrate and uranyl nitrate; and the co-denitration facility, in which the plutonium nitrate and uranyl nitrate are combined and converted to mixed oxide. The NRTA study itself comprises three tasks: Task 4, Modification and/or Extension of NRTA Simulation Techniques; Task 5, Development of Anomaly Detection Methodology; and Task 6, Conceptual Design for NDA Instruments. Two of these tasks are described below.

1. Task 4: Modification and/or Extension of NRTA Simulation Techniques. RRP is to be a large-scale facility with an annual throughput of hundreds of metric tons of heavy metal containing several metric tons of plutonium. In-process plutonium inventories are on the order of hundreds of kilograms in the main process area and also

TABLE XII. Measurement of Uranium Solution Standards						
Standard	Cell (cm)	Known Conc. (g/L)	Number of runs	Measured Uranium Concentration (g/L)		Ratio (M/Known)
1	2	60.26	5	60.032	± 0.20%	0.996
	2	60.26	5	59.992	± 0.21%	0.996
2	2	115.33	5	114.908	± 0.13%	0.996
	2	115.33	5	115.479	± 0.12%	1.001
3	2	180.19	5	179.497	± 0.1%	0.996
	2	180.19	5	179.878	± 0.1%	0.998
4	2	358.88	5	355.812	± 0.10%	0.991
5	4	32.84	5	33.100	± 0.23%	1.008
	4	32.84	5	33.099	± 0.22%	1.008
6	4	60.26	5	60.600	± 0.15%	1.006
	4	60.26	5	60.364	± 0.15%	1.002
7	4	115.33	5	116.145	± 0.11%	1.007
	4	115.33	5	115.932	± 0.13%	1.005
8	4	180.19	5	182.132	± 0.13%	1.011
	4	180.19	5	182.331	± 0.13%	1.012

in the co-denitration process. In a previous study, FacSim models were developed for the main process area and the co-denitration facility that described material amounts and flows with good accuracy. In the current multi-year task these previous simulation results are being improved in several ways:

- The description of process equipment and operating procedures in the FacSim data files has been made more accurate by adding volumes for pipe that connects process vessels and by using more exact values for vessel parameters such as volumes. This improvement is possible because JNFL has supplied additional process information to Los Alamos.
- More accurate descriptions of the properties of solvent-extraction processes are being added to FacSim. The enhanced versions use more detailed descriptions of the interior states of the processes and improved parameterizations of their hydro- and chemical dynamics.
- Improved differential-equation integration methods are being implemented that will reduce the dimensionality of the problem and handle moderately stiff sets of equations.
- The description of the co-denitration facility is being improved by using the newly developed batch-processing features of FacSim.

2. Task 5: Development of Anomaly Detection Methodology. During FY 1993 and FY 1994, we experimented with eight tests applied to sequences of simulated

monthly material balances that were similar to what is expected at Rokkasho. Because of the large throughput planned for Rokkasho, conventional NRTA based on approximately monthly inventories will need to be enhanced by closing material balances around individual process vessels after each material transfer. During FY 1995 we will begin working on issues that will arise when frequent balances are computed around individual process vessels.

The operator's capability to measure tank level, density, and temperature will be exploited to perform the balance closures by empirically relating measured concentration to density for each of several temperature ranges. We therefore anticipate performing very frequent, but relatively inaccurate (density can predict concentration to perhaps within 5%), balance closures to supplement more accurate balance closures based on analytical measurements of concentration. Because the more accurate analytical measurements of plutonium concentration are labor intensive, we continue to anticipate that the concentration for in-process vessels will be measured approximately once per month.

Because of the frequent balance closures around many individual vessels, it will be necessary to choose good statistical process monitoring methods that will both detect anomalies well and make the most use of all the data. Having that goal, we experimented with a multivariate version of Page's cusum test and reported on its performance in Ref. 88. Our results with the multivariate Page's cusum test are very promising, but with the one technical difficulty that the covariance matrix of the material balances must be specified. This can be done using measurement control information together with variance propagation, or using strictly empirical methods. (That is, estimate the

covariance matrix of the material balances across each vessel by analyzing a sequence of several hundred material balances for each vessel.) We plan to use both methods to estimate the covariance matrix. That will support the measurement error models in use as well as help to implement the multivariate cusum.

V. OTHER PROJECTS

A. Software Toolkit for Analysis Research (STAR) (J. E. Doak, J. M. Prommel, NIS-7; B. L. Hoffbauer, CIC-12)

Introduction. The goal of STAR is to produce a research tool that facilitates the development and interchange of algorithms for locating phenomena of interest in large quantities of data. Using this toolkit, researchers will be able to ascertain which existing techniques are the most promising, develop new and possibly more effective methods, and add or delete algorithms without major re-design work. This is a cost-effective method of developing software.

Some modules or components of STAR will preprocess incoming data; some will select which information is appropriate for a particular application; some will analyze data to uncover items of significance; and others will assess the effectiveness of the various components. Some of the specific techniques employed by the various modules will be feature selection algorithms, machine learning algorithms, a pure statistical model, and expert system methodologies. Ultimately, STAR will contain algorithms to perform outcome synthesis: the application of decision theory and risk analysis to conflicting conclusions from the modules.

Ultimately, STAR will also contain algorithms to synthesize the outcomes of concurrent analyses. These algorithms will use decision theory and risk analysis to arbitrate conflicting conclusions from various analysis modules. All components will be built upon firm theoretical support. We will also define measures by which we can evaluate the effectiveness of the various components and will develop software to calculate these measures. Each module will be separately compiled to enable quick-turnaround when changes are made.

During this year we addressed two diverse problems: developing prototype software for each of our funding agencies: the NSA and DOE/NN-20 Office of Arms Control and Nonproliferation. Both sets of software were demonstrated in October. Although the focus of our work has been in these two areas, the methodology used by STAR can be carried over to other problem domains.

The Problem. Huge data storage capacities have made it possible to formulate large integrated databases comprising many terabytes of information spanning a variety of subjects. The ability to analyze such vast quantities of data, which may come from diverse sources, is much sought after. Although the process of accessing the data

has become increasingly automated, the laborious task of assimilating, integrating, and interpreting the information still largely remains with a human analyst. However, with the advent of fast computers, we now have the capability to automate this process, thereby shifting the burden away from the analysts. Unfortunately, the algorithms that instruct computers on how to automatically manipulate such large databases and effectively process their information have not been extensively applied in numerous domains.

There are several reasons why these methodologies have not been widely applied. One is that many of the systems designed to solve problems relating to data analysis are strongly connected to their application. This makes it difficult to re-tool the systems to use alternative approaches and prevents comparing the effectiveness of various algorithms. Furthermore, much of the analysis research lacks a precise definition of the problem, increasing the difficulty of formulating well-defined, coherent goals for which formal solutions can be developed in a structured, incremental fashion. In many cases, this has resulted in a series of ad hoc approaches that—despite solving specific problems—are not well founded in a general theoretical framework. Without such a framework, it is extremely difficult to apply multiple analysis methodologies to a particular problem to determine their relative effectiveness.

Given our goal to develop an analysis toolkit, one might conclude that only algorithms that perform analysis will be developed under this project. However, that is not the case for two reasons. First, no matter what analysis methodology is developed, one needs to have a means of determining objective measures of effectiveness. Algorithms must be defined that calculate these measures of effectiveness. Second, all methods require that an effective set of features be extracted from raw data sources. This will involve algorithms, for example, that cluster the values of features, create new features by combining existing features, and select the most effective features for a given application. Both of these areas pose challenging research problems; STAR will be a platform that allows the research of these algorithms as well.

Knowledge Fusion Application. For the Knowledge Fusion Project and our NN-20 client, our emphasis was on developing special-purpose software for analysis of data for the Space and Atmospheric Burst Reporting System (SABRS) project. The primary objective of this project in 1994 was to analyze output from particle and radiation detectors on-board satellites to look for clandestine nuclear detonations (nudets). Currently, most of the data analysis and anomaly resolution activities occur only after the detector outputs are received by the ground station. However, much greater on-board processing capability than is currently implemented will be required on future satellites. Downloading of information must be kept to a minimum on these satellites as they will be shared among many applications.

Our role was to provide a software environment in which analysts can develop and optimize computational

algorithms required for on-board processing. This environment would be used to test the effectiveness of these methods against simulated data sets, to minimize the false alarm rate, and to determine which of the sensors are the most useful in detecting detonations. In the future, we will work with the designers of on-board systems to develop hardware that can efficiently implement these computational algorithms.

We produced a demonstration to show the software that is being used to achieve this goal. The demonstration was developed to (1) illustrate the software that we have developed, (2) showcase the visual programming environment we used for development, (3) demonstrate why the toolkit approach we adopted has merit, (4) illustrate the challenges and hurdles, and (5) explain our strategy for meeting these challenges in our future work.

This demonstration and the one we produced for NSA were built using the Khoros2 programming environment, which is a software integration and development environment that emphasizes information processing and data exploration. The goal of the Khoros software is to provide a complete application development environment that redefines the software engineering process to include all members of the project group, from the user of the application to the infrastructure programmer.

Audit Analysis Application. For NSA, we concentrated on developing the data structures (known as classes in object-oriented software) for two modules, the Data Acquisition module and the Information Preparation module. The problem domain is the analysis of a computer security audit trail. The end goal is to develop machine learning techniques and an expert system that will be used to identify potential computer misuse.

Whereas the SABRS data were homogeneous (readings from particle and radiation detectors on-board satellites in the form of arrays of real numbers), the data from an audit trail used by NSA consist of many diverse types, including variable-length free text and formatted real numbers. To perform reasonable analysis, input data must be transformed into features containing relevant information. This is the role of the Information Preparation module. Phase I of this module covers parsing, rationalization (methods for dealing with missing or erroneous data), value aggregation (including clustering methods where suitable), and abstraction of features (for example, combining features to make them more useful for analysis). Additional information on STAR modules appears in Ref 89.

This year we successfully demonstrated that we can handle any type of data in the Information Preparation module. We completed the design of the Data Acquisition and Information Preparation modules and demonstrated our implementation. Our software is written in the object-oriented language C++. We have also produced design documents and detailed functional specifications for some of the phases of our development.

B. Plutonium Disposition (D. Rutherford, NIS/SG; R. Moya, D. Mangan, R. Syler, R. Dugan, C. Jaeger, J. Matter, K. Tolk, and J. Moyer, SNL; S. Strait and L. Moore, LLNL; D. Close and B. Partain, NIS-6; and J. T. Markin, D. Wilkey, B. Erkkila, and B. Fearey, NIS-7; J. Craig and P. Robinson, NM)

The President outlined national policy in September 1993 that would seek to eliminate, where possible, the accumulation of surplus stockpiles of HEU or plutonium and other materials as defined by the Notice of Intent (Federal Register/Vol. 59, No. 118, Tuesday, June 21, 1994) and to ensure that where these materials already exist, they are subject to the highest standards for safety, security, and international accountability. The President called upon the Government to begin a comprehensive review of long-term options for fissile material disposition, taking into account technical, nonproliferation, environmental, budgetary, and economic issues.

At the request of the President's National Security Advisor and sponsored by the DOE, the National Academy of Sciences (NAS) conducted a study of the options for achieving long-term disposition of the excess plutonium from the dismantlement of nuclear weapons. The NAS published their report in 1994, entitled "Management and Disposition of Excess Weapons Plutonium."

The NAS report recommended that the US and Russia pursue long-term plutonium options that

- minimize the time during which plutonium is stored in usable forms,
- preserve high standards of safeguards and security during any disposition process,
- result in a form from which recovery would be difficult, and
- meet high standards of protection for public and worker health and for the environment.

Motivated by the results of the NAS report, the DOE has established a program, Fissile Material Disposition Project (FMDP), to address the disposition options applicable to surplus fissile material. The first step was to publish the Notice of Intent in the Federal Register on Tuesday, June 21, 1994, to prepare a Programmatic Environmental Impact Statement (PEIS) for the storage and disposition of weapons-usable fissile materials. This is to be completed by August 1995 followed by the preparation of a preconceptual definition of each of the technologies or facilities being considered for the disposition options. This will result in a fissile material disposition Record of Decision (ROD) in August 1996. The technology options being considered include the following:

- Accelerator-Based Conversion Technologies,
- Direct Geologic Disposition,

- Immobilization,
- Alternative Materials Storage,
- Nuclear Fuels Technologies,
- Pit Disassembly and Conversion,
- Plutonium Storage,
- Reactor-Based Technologies,
- Uranium Storage and Disposition - ²³³U, and
- Uranium Storage and Disposition - HEU.

The S&S activity for this program is an important cross-cutting task that is required to be addressed for all of the FMDP options. Two distinct areas will be considered for each facility/technology option: international safeguards and domestic S&S. International safeguards traditionally comprises two subsystems: nuclear materials accountancy and material containment and surveillance. Domestic safeguards and security likewise traditionally comprises two subsystems: nuclear materials control and accounting and the physical measures required to protect nuclear materials against threats of theft, diversion, and radiological sabotage. International safeguards plays a key role in the FMDP. Under PDD-13 (Presidential Decision Directive), the US initiative will be to place surplus fissile material under IAEA safeguards. The S&S cross-cutting task must evaluate the technical options for IAEA inspection of this material while evaluating the various options/facilities. Recent technological developments will need to be considered to serve both the needs of domestic safeguards and international safeguards for the various technology options being considered in the FMDP.

Overall safety requirements are to be determined by the facility/technology teams. However, the S&S team will carefully consider the safety requirements in addressing safeguards and security alternatives to ensure, at a minimum, that safety requirements are satisfied, or better yet, incorporate features that help ensure a higher degree of safety protection for the environment or the people. The S&S solutions prepared will depend strongly on the information provided by the facility/technology teams.

1. Stakeholders. The key to the success of this project, as well as the overall FMDP program, is a clear understanding of the major stakeholders for the S&S project. The S&S team has identified a list of stakeholders. The S&S team recognizes the stakeholders denoted with an asterisk as having ownership in this program, having related interest in this program, owning programs that could be impacted by the results of this program, or otherwise having significant influence on decisions made in the DOE on the safeguards and security of fissile material.

- *a. The Public
- *b. The DOE: NM, EM, DP, NN, and NE Offices
- *c. The PEIS Contractor
- *d. Facility/Technology Teams
- *e. The Integration Team

- f. DOE Maintenance and Operations Contractors and Environmental Restoration and Waste Management Contractors
- g. US Administration Policy Makers
- h. FSU - Russia
- i. Other nuclear & non-nuclear nations
- j. NRC
- k. EPA
- l. IAEA

To properly represent the best interests of these stakeholders, specific assignments will be made to S&S members for interfacing and understanding the issues and concerns of the stakeholders. More than one member may be assigned to each stakeholder to maximize the opportunities for maintaining a positive working relationship with the stakeholders.

2. Goals and Objectives. The goal for this project is to compile and analyze the applications of S&S for each of the facilities/technologies that will provide information useful for the PEIS and the ROD process. The objectives defined that will enable accomplishing this goal include the following:

- a. Develop the project plan and coordinate project activities.
- b. Identify the S&S requirements for each facility/technology.
- c. Compile data on forms of material in and process operations for each facility.
- d. Evaluate facilities/technologies for S&S risks.
- e. Evaluate facilities/technologies for achieving international safeguards goals.
- f. Identify and evaluate S&S discriminators
- g. Actively participate with facility teams and public awareness teams.
- h. Prepare the S&S section for each facility/technology report.
- i. Coordinate with the proliferation team to identify S&S issues related to nonproliferation and bilateral agreements.

Specific tasks detailing each of these objectives compose the major part of the project plan document.

3. Project Plan. The project plan shall be the governing document for the activities to be done by the S&S team in support of the facilities/technologies. These activities are focused on achieving two major milestones as stated earlier: the publication of the PEIS in August 1995 and the publication of the documents required for the ROD in August 1996. The project plan shall define those elements necessary to maintain effective communication between the team members as well as effect the specific tasks that need to be done to accomplish the two major milestones noted above.

The ownership of this project plan is jointly shared by Ron Moya at SNLA (505-844-3163) and Debra

*Primary Stakeholders.

Rutherford at LANL (505-665-5038). Any comments, changes, corrections, and additions shall be directed to one of these individuals.

The following are the specific tasks defined for the implementation of this project plan.

- (a) Develop project goal and objectives.
- (b) Develop project tasks for each objective with owners, task output, and beginning and end dates.
- (c) Coordinate activities and execute the plan.
- (d) Define a communication standard plan for the project.
- (e) Define a document control standard plan for the project.
- (f) Document and distribute the plan.
- (g) Maintain the plan; update and revise as necessary.

The following defines the tasks that are required to accomplish each of the objectives defined above. Each task is defined with the following information:

- (a) Brief description statement
- (b) Task owner
- (c) Expected output and metrics
- (d) Date for task to begin
- (e) Date for task to be completed
- (f) List of predecessor tasks

A summary of the milestones and deliverables for this project is presented in Appendix II of the Project Plan.

C. Support to the Los Alamos Operational Safeguards Group (FSS-12) (D. D. Wilkey, B. H. Erkkila, N. R. Zack, and K. E. Thomas, NIS-7; J. K. Sprinkle, Jr., NIS-5)

We assisted FSS-12 in preparing for the September 1994 inspection and evaluation of Los Alamos safeguards and security by the DOE. Areas for which support was provided included MC&A documentation, physical inventories, inventory difference evaluation, measurement and measurement control, internal review and assessment, and performance testing. Support to FSS-12 is expected to continue during FY 1995, primarily by assisting with the internal reviews of MC&A functions.

D. Weapons Complex Reconfiguration (N. R. Zack, W. J. Huntman, and D. D. Wilkey, NIS-7; P. M. Rinard, NIS-5)

The Safeguards Systems and Safeguards Assay Groups functioned as key participants in the Safeguards and Security Team for the DOE's Office of Weapons Complex Reconfiguration (OWCR). The safeguards groups at Los Alamos helped to complete the materials control and

accountability, computer/information security, and the assay/measurement systems portions of the *Weapon's Complex Reconfiguration Programmatic Design Criteria* for the plutonium, uranium, tritium, and non-nuclear facilities and operations. We provided improved designs and applications of existing safeguards systems and operational considerations for implementation into the specific facilities in the nuclear materials complex; for example, the proposed plutonium storage facility and the existing tritium recovery and recycle facilities. These improved or new methods were designed to increase efficiency and be cost effective while supporting radiation-dose-reduction initiatives. The resulting safeguards and security systems have been structured to permit international and bilateral inspection activities at the SNM facilities of the OWCR while minimizing the impact on facility protection program and operational requirements. The Los Alamos team participated in finalizing the design for the new uranium and plutonium storage and processing facilities. We provided information and data for the S&S assessments on the various production, recovery, and recycle options discussed in the *Programmatic Environmental Impact Statement*.

We participated in the preparation of an information "white paper" for the Office of Reconfiguration that identified and explained the safeguards and security requirements that would be required for production of tritium from advanced LWRs and commercial LWRs. We are preparing additional information papers concerning the safeguards and information/computer security requirements for stand-alone supplies of tritium and for the accelerator production of tritium.

E. Policy Studies on an SNM Production Cutoff (W. D. Stanbro and C. T. Olinger, NIS-7)

In September 1993, President Clinton called for a universal, nondiscriminatory, internationally verifiable ban on the production of SNM for use in nuclear explosive devices or outside of safeguards. Such an agreement, if enacted, would significantly extend the current international nonproliferation regime by capping the production of plutonium and HEU for weapons. An international agreement to bring about this goal is under consideration at the Conference on Disarmament in Geneva, Switzerland.

At the request of the DOE Arms Control Negotiations and Analysis Division (NN-41), the Safeguards Systems Group has been involved in several studies to define the scope and verification regime for such an agreement. These studies have included the preparation of white papers and briefings for the Interagency Working Group involved in developing US policy on a cutoff regime, preparation of technical support material for negotiators, and a mock inspection exercise.

Because plutonium production will probably be defined as the separation of the element from fission products, inspections of reprocessing plants will form an inte-

gral part of the inspection regime. It is likely that several old reprocessing plants in the current NPT weapons states (US, U.K., France, Russia, and China) will be subject to the provisions of a cutoff agreement. These facilities were built with no provision made for verifying their operation by international inspectors. In several cases they are much larger than reprocessing plants currently under international inspection by the IAEA. An example of such a facility is the PUREX reprocessing plant at Hanford, Washington. The PUREX plant started operation in 1956 to separate plutonium for the US nuclear weapons program. It operated on and off until 1990. PUREX was the world's largest reprocessing plant and produced much of the plutonium used in US weapons. It is currently being cleaned out and placed in a configuration in which it can be left with minimal attention until it is dismantled sometime in the future. The present state of the PUREX facility made it an ideal laboratory to investigate schemes for verification of a plutonium production cutoff.

The PUREX exercise was carried out to learn more about the challenges of inspecting large, old reprocessing plants like PUREX and to evaluate alternative means of carrying out these inspections. The exercise involved assembling a group of experts familiar with reprocessing, international safeguards, and arms control at PUREX. They were divided into three teams: a facilities team, an inspection team, and a control team. The facilities team was responsible for preparing a description of the facility and representing a facility viewpoint during the exercise. The facility description took the form of an IAEA Design Information Questionnaire. The Design Information Questionnaire formed the basis of a series of inspection plans developed by the inspection team. These were presented during the exercise and the facility team was allowed to comment on their feasibility. The control team was responsible for maintaining the flow of the exercise and documenting the results. Alternative inspection methods were further evaluated at an additional session at Los Alamos.

The results of the PUREX exercise reinforced concern about the costs associated with inspections of these

types of facilities if they were operating to produce civilian plutonium for nuclear power generation, which is allowed under the treaty. For plants in the process of being cleaned up or abandoned, verification would be considerably easier. The exercise considered some promising options to traditional materials-accounting-based verification, but the acceptability of these measures will depend on the negotiated goals of a cutoff agreement.

F. Bilateral Plutonium Production Ban (W. D. Stanbro, NIS-7)

On June 23, 1994, an agreement was signed between the US and the Russian Federation to shut down any operating plutonium production reactors by the year 2000 and to prevent the restart of already shut down plutonium production reactors. The only currently operating production reactors are three in the Russian Federation. The agreement prohibits plutonium produced by these reactors from being used for nuclear weapons. The details of the verification regime are to be worked out within six months of signing the agreement.

At the request of NN-41, Los Alamos, in cooperation with other national laboratories, has been engaged in a series of studies to develop the verification regime and provide estimates of the cost. The current verification plan involves a joint effort by the US and the Russians to develop mutually agreed upon models to estimate the plutonium production as a function of reactor power. Reactor power levels would be confirmed with flow and temperature measurements made by US instrumentation. Once the predicted plutonium production numbers were agreed to by both parties, the Russians would be required to place this amount of plutonium in monitored storage. Nondestructive assay measurements of the plutonium isotopic composition and americium content would be made to ensure that the material presented for storage had come from the subject reactors.

Publications/Presentations

PUBLICATIONS/PRESENTATIONS

G. Anzelon, R. V. Badalamente, S. M. DeLand, and R. Whiteson, "Determining Information Management Needs for Enhanced International Safeguards," *Nucl. Mater. Manage.* XXIII, 372-377 (1994).

The Safeguards Information Management System initiative is a program of the Department of Energy's (DOE) Office of Arms Control and Nonproliferation aimed at supporting the International Atomic Energy Agency's (IAEA) efforts to strengthen safeguards through the enhancement of information management capabilities. The DOE hopes to provide the IAEA with the ability to correlate and analyze data from existing and new sources of information, including publicly available information, information on imports and exports, design information, environmental monitoring data, and non-safeguards information. The first step in this effort is to identify and define IAEA requirements. In support of this, we have created a users' requirements document based on interviews with IAEA staff that describes the information management needs of the end user projected by the IAEA, including needs for storage, retrieval, analysis, communication, and visualization of data. Also included are characteristics of the end user and attributes of the current environment. This paper describes our efforts to obtain the required information. We discuss how to accurately represent user needs and involve users for an international organization with a multi-cultural user population. We describe our approach, our experience in setting up and conducting the interviews and brainstorming sessions, and a brief discussion of what we learned.

Q. D. Appert, M. H. West, D. B. Court, P. A. Russo, M. M. Moy, M. M. Martinez, and M. K. Romero, "Experiments on the Fluorination of Plutonium Dioxide Using a Stirred-Bed Reactor and Continuous Neutron Monitor," Los Alamos National Laboratory report LA-12640 (March 1994). Not for Public Dissemination (Limited Access)

At Los Alamos, fluorination of plutonium dioxide (PuO_2) is typically performed in a static bed reactor with an Inconel 600 frit. After one fluorination with hydrogen fluoride (HF), the product is unevenly fluorinated and is not free flowing and therefore cannot be readily transferred to the dumper-mixer assembly. Various stirrer designs were evaluated to investigate improving gas-solid interaction and

providing a free-flowing product. The neutron flux arising from the alpha-neutron reaction between plutonium and fluorine in plutonium tetrafluoride (PuF_4) was measured by a continuous neutron monitor and was used to monitor the conversion from PuO_2 to PuF_4 . A quantitative measure of the conversion is possible, and reagent consumption can be optimized by halting fluorination when adequate conversion is reached. Thus, HF and aqueous potassium hydroxide (KOH) (scrubbing) solution usage can be subjected to waste minimization with the continuous neutron monitor as an at-line process control technique. All experiments employed full-scale fluorinations.

S. C. Bourret and M. S. Krick, "A Dead Time Reduction Circuit for Thermal, Neutron Coincidence Counters with Amptek Preamplifiers," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 646-650 (1994).

We have developed a deadtime reduction circuit for thermal neutron coincidence counters using Amptek preamplifier/amplifier/discriminator circuits. The principle is to remove the overlap between the output pulses from the Amptek circuits by adding a derandomizer between the Amptek circuits and the shift-register coincidence electronics. We implemented the derandomizer as an Actel programmable logic array; the derandomizer board is small and can be mounted in the high-voltage junction box with the Amptek circuits, if desired. Up to 32 Amptek circuits can be used with one derandomizer. The derandomizer has seven outputs: four groups of eight inputs, two groups of 16 inputs, and one group of 32 inputs. We selected these groupings to facilitate detector ring-ratio measurements. The circuit was tested with the five-ring research multiplicity counter, which has five output signals—one for each ring. The counter's deadtime was reduced from 70 to 30 ns.

J. N. Bradley, C. M. Brislawn, J. E. Brown, C. A. Rodriguez, and L. A. Stoltz, "Video Imaging for Nuclear Safeguards," presented at the Industrial Data Compression Workshop and Conference (IEEE), Snow Bird, Utah, March 30–April 1, 1994. Los Alamos National Laboratory document LA-UR-94-1077.

No abstract

D. A. Burns, "Plutonium Solution Analyzer," Los Alamos National Laboratory report LA-12843-MS (September 1994).

A fully automated analyzer has been developed for plutonium solutions. It was assembled from several commercially available modules, is based upon segmented flow analysis, and exhibits precision about an order of magnitude better than commercial units (0.5%-0.05% RSD). The system was designed to accept unmeasured, untreated liquid samples in the concentration range 40-240 g/L and produce a report with sample identification, sample concentrations, and an abundance of statistics. Optional hydraulics can accommodate samples in the concentration range 0.4-4.0 g/L. Operating at a typical rate of 30 to 40 samples per hour, it consumes only 0.074 mL of each sample and standard, and generates waste at the rate of about 1.5 mL per minute. No radioactive material passes through its multichannel peristaltic pump (which remains outside the glovebox, uncontaminated) but rather is handled by a 6-port, 2-position chromatography-type loop valve. An accompanying computer is programmed in QuickBASIC 4.5 to provide both instrument control and data reduction. The program is truly user-friendly and communication between operator and instrument is via computer screen displays and keyboard. Two important issues which have been addressed are waste minimization and operator safety (the analyzer can run in the absence of an operator, once its autosampler has been loaded).

T. L. Burr and L. E. Wangen, "Process Fault Detection and Nonlinear Time Series Analysis for Anomaly Detection in Safeguards," presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994. Los Alamos National Laboratory document LA-UR-94-171.

In this paper we discuss process fault detection and nonlinear time series analysis, and apply them to the analysis of vector-valued and single-valued time-series data. We investigate model-based process fault detection methods for analyzing simulated, multivariate, time-series data from a three-tank system. The model-predictions are compared with simulated measurements of the same variables to form residual vectors that are tested for the presence of faults (possible diversions in safeguards terminology). We evaluate two methods, testing all individual residuals with a univariate z-score and testing all variables simultaneously with the Mahalanobis distance, for their ability to detect loss of material from two different leak scenarios from the three-tank system: a

leak without and with replacement of the lost volume. Nonlinear time-series analysis tools were compared with the linear methods popularized by Box and Jenkins. We compare prediction results using three nonlinear and two linear modeling methods on each of six simulated time series: two nonlinear and four linear. The nonlinear methods performed better at predicting the nonlinear time series and did as well as the linear methods at predicting the linear values.

T. L. Burr, "Predicting Linear and Nonlinear Time Series with Applications in Nuclear Safeguards and Nonproliferation," Los Alamos National Laboratory report LA-12766-MS (April 1994).

This report is a primer on the analysis of both linear and nonlinear time series with applications in nuclear safeguards and nonproliferation. We analyze eight simulated and two real time series using both linear and nonlinear modeling techniques. The theoretical treatment is brief but references to pertinent theory are provided. Forecasting is our main goal. However, because our most common approach is to fit models to the data, we also emphasize checking model adequacy by analyzing forecast errors for serial correlation or nonconstant variance.

T. Burr, "Material Balance Areas and Frequencies for Large Reprocessing Plants," *Nucl. Mater. Manage.* XXIII, 970-977 (1994).

It has long been recognized that facilities with a large nuclear material throughput will probably not meet the International Atomic Energy Agency (IAEA) goal for detecting trickle diversion of plutonium over periods of about one year. The reason is that measurement errors for plutonium concentration and for liquid volume are often approximately relative over a fairly wide range of true values. Therefore, large throughput facilities will tend to have large uncertainties assigned to their annual throughput. By the same argument, if frequent balances are performed over small material balance areas, then the uncertainty associated with each balance period for each balance area will be small. However, trickle diversion would still be difficult to detect statistically. Because the IAEA will soon be faced with safeguarding a new large-scale reprocessing plant in Japan, it is timely to reconsider the advantages and disadvantages of performing frequent material balances over small balance areas (individual tanks where feasible). Therefore, in this paper we present some simulation

results to study the effect of balance frequency on loss detection probability, and further simulation results to study possibilities introduced by choosing small balance areas. We conclude by recommending frequent balances over small areas.

T. Burr, J. Jones, and L. Wangen, "Multivariate Diagnostics and Anomaly Detection for Nuclear Safeguards," *Nucl. Mater. Manage.* XXIII, 1000-1007 (1994).

We first review recent literature that applies multivariate Shewhart and multivariate cumulative sum (Cusum) tests to detect anomalous data. These tests are used to evaluate residuals obtained from a simulated three-tank problem in which five variables (volume, density, and concentrations of uranium, plutonium, and nitric acid) in each tank are modeled and measured. We then present results from several simulations involving transfers between the tanks and between the tanks and the environment. Residuals from a no-fault problem in which the measurements and model predictions are both correct are used to develop Cusum test parameters which are then used to test for faults for several simulated anomalous situations, such as an unknown leak or diversion of material from one of the tanks. The leak can be detected by comparing measurements, which estimate the true state of the tank system, with the model predictions, which estimate the state of the tank system as it "should" be. The no-fault simulation compares false alarm behavior for the various tests, whereas the anomalous problems allow us to compare the power of the various tests to detect faults under possible diversion scenarios. For comparison with the multivariate tests, univariate tests are also applied to the residuals.

P. Chare, J. Goerten, Hans Wagner, C. Rodriguez, and J. E. Brown, "Unattended Digital Video Surveillance: A System Prototype for EURATOM Safeguards," *Nucl. Mater. Manage.* XXIII, 1024-1029 (1994).

Ever increasing capabilities in video and computer technology have changed the face of video surveillance. From yesterday's film and analog video tape-based systems, we now emerge into the digital era with surveillance systems capable of digital image processing, image analysis, decision control logic, and random data access features—all of which provide greater versatility with the potential for increased effectiveness in video surveillance. Digital systems also offer other advantages such as the ability to "compress" data, providing increased storage capacities and the potential for allowing longer surveillance periods. Remote surveillance and system

to system communications are also a benefit that can be derived from digital surveillance systems. All of these features are extremely important in today's climate of increasing safeguards activity and decreasing budgets. Los Alamos National Laboratory's Safeguards Systems Group and the EURATOM Safeguards Directorate have teamed to design and implement a prototype surveillance system that will take advantage of the versatility of digital video for facility surveillance and data review. In this paper we will familiarize you with system components and features and report on progress in developmental areas such as image compression and region of interest processing.

J. Claborn and A. Avarado, "LANMAS Core: Update and Current Directions," *Nucl. Mater. Manage.* XXIII, 313-317 (1994).

Local Area Network Material Accountability System (LANMAS) core software will provide the framework of a material accountability system. LANMAS is a network-based nuclear material accountability system. It tracks the movement of material throughout a site and generates the required reports on material accountability. LANMAS will run in a client/ server mode. The database of material type and location will reside on the server, while the user interface runs on the client. The user interface accesses the server via a network. The LANMAS core can be used as the foundation for building required Materials Control and Accountability (MC&A) functionality at any site requiring a new MC&A system. An individual site will build on the LANMAS core by supplying site-specific software. This paper will provide an update on the current LANMAS development activities and discuss the current direction of the LANMAS project.

D. W. Crawford and N. R. Zack, "Domestic Safeguards Implications of International Inspections of Excess Fissile Materials," presented at the INMM Non-Proliferation and Arms Control Seminar, Washington, DC, April 6-7, 1994. Los Alamos National Laboratory document LA-UR-94-1152.

This paper presents issues and views associated with the recent offer by the United States to place fissile nuclear materials excess to its national deterrent under International Atomic Energy Agency (IAEA) safeguards inspection. Specifically, the implications of this offer will be discussed in the context of domestic security and current Department of Energy (DOE) safeguards policies and procedures. This paper does not suggest that placing such materials

under international inspection is desirable. Instead, it is intended to discuss in broad terms the importance of careful consideration as to what elements of inspection are concluded between the United States and the IAEA as to not compromise legitimate national security, operational, and health and safety concerns with the DOE.

D. W. Crawford and N. R. Zack, "MC&A Policy Issues for International Inspections at DOE Nuclear Facilities," *Nucl. Mater. Manage.* XXIII, 515-518 (1994).

Recent initiatives and executive decisions within the US have included an offer to place certain special nuclear materials from the former weapons stockpile under international safeguards inspections. The nuclear materials at issue are excess materials; other materials characterized as strategic reserve will not be subject to these international activities. Current Department of Energy requirements and procedures to account for and control these nuclear materials may need to be modified to accommodate these inspections. Safeguards issues, such as physical inventory frequency and verification requirements, may arise from the collateral safeguards activities in support of both domestic and international safeguards. This paper will discuss Office of Safeguards and Security policy and views on these international inspection activities at former nuclear weapons facilities, including implications for current domestic safeguards approaches currently implemented at these facilities.

C. A. Coulter, "User's Manual: Simulation Program FacSim Version 2.0," Los Alamos National Laboratory, Safeguards Systems Group report N-4/94-974 (September 20, 1994).

No abstract.

J. Doak, J. Prommel, and B. Hoffbauer, "Using STAR to Solve a Nonproliferation Problem" *Nucl. Mater. Manage.* XXIII, 789-793 (1994).

STAR (Software Toolkit for Analysis Research) is a research tool that provides an infrastructure for rapidly developing analysis techniques and evaluating their effectiveness. One of the problem domains that we are using to aid in the development of STAR is the exploitation of remote sensing data to detect proliferation. This paper will present an overview of this problem domain including the goals of analysis, the data being used, and the model of behavior

that we are attempting to detect. We will also discuss the status of STAR software development.

B. H. Erkkila, "Auditing for Safeguards Performance," *Nucl. Mater. Manage.* XXIII, 1216-1218 (1994).

Department of Energy (DOE) Orders and draft orders for nuclear material control and accountability (MC&A) address a complete MC&A program for all DOE contractors processing, using, or storing nuclear materials. Performance is a significant element of the DOE requirements for good MC&A. MC&A programs must address how well the contractor implements the various elements of the program including performance monitoring and testing. The contractor needs to measure and audit this performance in preparation for oversight auditing performed by the DOE audit teams and any other outside audits performed by government agencies. The oversight audit teams also have to measure and audit the performance level of the contractor to assure that the MC&A programs comply with the performance requirements. This paper discusses several ways the contractor and the DOE auditors can address the task of auditing for performance.

B. H. Erkkila and F. Kelso, "MASS—An Automated Accountability System," *Nucl. Mater. Manage.* XXIII, 300-303 (1994).

All Department of Energy contractors who manage accountable quantities of nuclear materials are required to implement an accountability system that tracks and records the activities associated with those materials. At Los Alamos, the automated accountability system allows data entry on computer terminals and data base updating as soon as the entry is made. It is also able to generate all required reports in a timely fashion. Over the last several years, the hardware and software have been upgraded to provide the users with all the capability needed to manage a large variety of operations with a wide variety of nuclear materials. Enhancements to the system are implemented as the needs of the users are identified. The system has grown with the expanded needs of the users and has survived several years of changing operations and activity. The user community served by this system includes processing, materials control and accountability, and nuclear material management personnel. In addition to serving the local users, the accountability system supports the national data base (NMMSS). This paper contains a discussion of several details of the system design

and operation. After several years of successful operation, this system provides an operating example of how computer systems can be used to manage a very dynamic data management problem.

R. I. Ewing, G. E. Bosler, R. Siebelist, and G. R. Walden, "Burnup Verification Measurements of Spent Fuel Assemblies at Oconee Nuclear Station," Los Alamos National Laboratory document LA-UR-94-61 (published as a report at Electric Power Research Institute).

The FORK measurement system has been used to examine spent fuel assemblies at the Oconee Nuclear Station of Duke Power Company. The neutron and gamma-ray emissions from individual spent fuel assemblies were measured in the storage pool after the assemblies were partially raised out of the storage rack. The tests were designed to demonstrate the ability of the FORK system to verify reactor records for burnup and cooling time, to detect deviations from those records, and to develop procedures for the use of the system that are compatible with utility operations. Ninety-three assemblies were examined in 3 1/2 days of operation. The variation in burnup along the length of the assembly was measured for two assemblies. The FORK measurements correlated satisfactorily with the Oconee reactor records. The average deviation of the burnup measurements from the calibration was 10% without corrections for initial enrichment, and 2.2% with corrections. Two anomalous assemblies were detected well outside these values. The system proved to be compatible with storage pool operations, and could be used most effectively to verify reactor records in a campaign involving a large number of assemblies. The test program was a cooperative effort involving Sandia National Laboratories, Los Alamos National Laboratory, Duke Power Company, and the Electric Power Research Institute.

P. E. Fehlau, "Integrated Neutron/Gamma-Ray Portal Monitors for Nuclear Safeguards," to be published in the IEEE Trans. Nucl. Sci., (August 1994).

Radiation monitoring is one nuclear safeguards measure used to protect against the theft of special nuclear materials (SNM) by pedestrians departing from SNM access areas. The integrated neutron/gamma-ray portal monitor is an ideal monitor for the task when the SNM is plutonium. It achieves high sensitivity for detecting both shielded and unshielded plutonium by combining two types of radiation detector. One type is a neutron-chamber detector comprising a large, hollow, neutron moderator with a central neutron proportional counter.

The entrance wall of the chamber is thin to make the detector undermoderated and quite sensitive to plutonium inside a moderating shield. The other walls of the chamber are thick enough to provide albedo neutrons that can migrate to the proportional counter, whether or not the plutonium is shielded. The other type is a plastic scintillation detector that is integrated into the chamber. Four scintillators either replace part of the thick chamber walls or are inserted into the chamber void. We compared the influence of the two methods of integration on detection of neutrons and gamma rays, and we examined the effectiveness of other design factors and methods for signal detection.

P. E. Fehlau and D. A. Rutherford, "A Status Report on the TSA Systems, Ltd., MCA465 Gamma-Ray Confirmation Instrument," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 635-639 (1994).

The TSA Systems, Ltd., MCA465 is a hand-portable, low resolution, gamma-ray instrument for confirming special nuclear materials (SNM) and related applications. The instrument evolved from earlier TSA Systems hand-held instruments, and, since its inception in 1991, it has been undergoing cycles of evaluation and then repair or redesign to correct problems. Through the efforts of Los Alamos, Rocky Flats, and TSA Systems, the MCA465 now has achieved commendable progress toward achieving quality performance as a rapid confirmation tool for SNM.

P. E. Fehlau, "A Survey Of SNM-Monitoring Practice And Needs," Los Alamos National Laboratory informal report NIS6-94:PEF, September 1, 1994.

Our Safeguards research task on Nuclear Materials Detection and Surveillance is driven by needs expressed by the DOE facilities that must protect special nuclear materials (SNM) from theft or diversion. Formal user needs submitted to the DOE Office of Safeguards and Security are one way that we learn of existing or emerging needs, and informal contacts with the individuals in need provide the essential details, including possible constraints on solutions. Informal contacts also can provide us with information on user needs that have not been directed through the formal process but none-the-less may become worthwhile projects. In addition, these direct contacts may give us an opportunity to suggest appropriate solutions based on relevant work that we have completed. To be sure that we are covering all the bases, we have periodically conducted a survey of facilities involved with protecting SNM to see how

well we are meeting established needs and to obtain feedback on how SNM monitors are working at the facility. In the following sections, this report describes the results of a facility survey completed during FY 1993.

J. F. Hafer and C. A. Coulter, "MAWST—Materials Accounting With Sequential Testing—A Windows Version," Los Alamos National Laboratory, Safeguards Systems Group report N-4/94-271 (March 1994).

This report describes the installation and execution of the Windows version of the computer code MAWST (Materials Accounting With Sequential Testing). The code can be run on a personal computer on which Microsoft Windows 3.1 is installed. A brief history of the MAWST code is provided for the reader who is not familiar with MAWST.

E. A. Hakkila and M. F. Mullen, "Reassessment of Safeguards Parameters," *Nucl. Mater. Manage.* XXIII, 138-145 (1994).

The International Atomic Energy Agency is reassessing the timeliness and goal quantity parameters that are used in defining safeguards approaches. This study reviews technology developments since the parameters were established in the 1970s and concludes that there is no reason to relax goal quantity or conversion time for reactor-grade plutonium relative to weapons-grade plutonium. For low-enriched uranium, especially in countries with advanced enrichment capability, there may be an incentive to shorten the detection time.

J. K. Halbig, S. C. Bourret, W. J. Hansen, D. V. Hicks, S. F. Klosterbuer, and M. S. Krick, "Portable Shift Register," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 487-493 (1994).

An electronics package for a small, battery-operated, self-contained, neutron coincidence counter based on a portable shift-register (PSR) has been developed. The counter was developed for applications not adequately addressed by commercial packages, including in-plant measurements to demonstrate compliance with regulations (domestic and international), in-plant process control, and in-field measurements (environmental monitoring or safeguards). Our package's features, which address these applications, include the following:

- small size for portability and ease of installation;
- battery or mains operation;

- a built-in battery to power the unit and a typical detector such as a small sample counter, for over 6 h if power lines are bad or noisy, if there is a temporary absence of power, or if portability is desired;
- complete support, including bias, for standard neutron detectors;
- a powerful communications package to easily facilitate robust external control over a serial port; and
- a C-library to simplify creating external control programs in computers or other controllers.

Whereas the PSR specifically addresses the applications mentioned above, it also performs all the measurements made by previous electronics packages for neutron coincidence counters developed at Los Alamos and commercialized. The PSR electronics package, exclusive of carrying handle, is 8 by 10 by 20 cm; it contains the circuit boards, battery, and bias supply and weighs less than 2 kg. This instrument package is the second in an emerging family of portable measurement instruments being developed; the first was the Miniature and Modular Multichannel Analyzer (M³CA). The PSR makes extensive use of hardware and software developed for the M³CA; like the M³CA, it is intended primarily for use with an external controller interfaced over a serial channel.

J. E. Halbig, K. E. Gainer, and S. F. Klosterbuer, "An Efficient Network for Interconnecting Remote Monitoring Instruments and Computers," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 825-833, (1994).

Remote monitoring instrumentation must be connected with computers and other instruments. The cost and intrusiveness of installing cables in new and existing plants presents problems for the facility and the International Atomic Energy Agency (IAEA). We have tested a network that could accomplish this interconnection using mass-produced commercial components developed for use in industrial applications. Unlike components in the hardware of most networks, the components—manufactured and distributed in North America, Europe, and Asia—lend themselves to small and low-powered applications. The heart of the network is a chip with three microprocessors and proprietary network software contained in Read Only Memory. In addition to all non-user levels of protocol, the software also contains message authentication capabilities. This chip can be interfaced to a variety of transmission media, for example, RS-485 lines, fiber optic cables, rf waves, and standard ac power lines. The use of power lines

as the transmission medium in a facility could significantly reduce cabling costs.

J. K. Halbig, S. F. Klosterbuer, P. A. Russo, J. K. Sprinkle, Jr., S. E. Smith, and Kiril Ianakiev, "Advances in and Uses of Gamma-Ray Field Instrumentation at Los Alamos," presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994, Los Alamos National Laboratory document LA-UR-94-276.

We are developing a set of tools to be used by the Safeguards Assay Group to solve problems found in safeguards and the domestic nuclear industry. The tools are also applicable to problems dealing with the environment, defense, and other areas of national and international interest.

We have used extensively the advances in hardware and software since our last multi-channel analyzer (MCA) development activities over a decade ago. We are also using our experience with and feedback from users of our previous instruments.

In analyzing the instrument needs of our constituents and the characteristics of our previous instruments, which we think have inhibited their broader use, we have concluded that

- uses for an MCA-type instrument are widely varied and fundamentally changing, and that any new instruments should include
- a versatile, widely used hardware interface, which is as independent as possible of hardware standards, and which is
- readily interfaced to the computers or controllers rapidly evolving in the commercial sector.

In addition, software tools must be provided that

- allow Los Alamos, users, and third parties to quickly and conveniently develop software specific to the user or the measurement to control the basic instrument we develop.

This paper deals mainly with a miniature and modular multi-channel analyzer (M³CA) and its applications.

L. M. Harris and W. J. Huntman, "A Systems Engineering Approach to AIS Accreditation," presented at the 16th DOE Computer Security Group Training Conference, Denver, Colorado, May 3-5, 1994. Los Alamos National Laboratory document LA-UR-94-911.

The systems engineering model provides the vehicle for communication between the developer and the

customer by presenting system facts and demonstrating the system in an organized form. The same model provides implementors with views of the system's function and capability.

The authors contend that the process of obtaining accreditation for a classified Automated Information System (AIS) adheres to the typical systems engineering model. The accreditation process is modeled as a "roadmap" with the customer represented by the Designated Accrediting Authority. The "roadmap" model reduces the amount of accreditation knowledge required of an AIS developer and maximizes the effectiveness of participation in the accreditation process by making the understanding of accreditation a natural consequence of applying the model. This paper identifies ten "destinations" on the "road" to accreditation. The significance of each "destination" is explained, as are the potential consequences of its exclusion.

The "roadmap," which has been applied to a range of information systems throughout the DOE community, establishes a paradigm for the certification and accreditation of classified AISs.

J. A. Howell, H. O. Menlove, G. W. Eccleston, R. Whiteson, C. A. Rodriguez, J. K. Halbig, S. F. Klosterbuer, and M. F. Mullen, "Safeguards Applications of Pattern Recognition and Neural Networks," presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994. Los Alamos National Laboratory document LA-UR-94-169.

The number, complexity, and throughput of nuclear materials is increasing at nuclear facilities all over the world. It is becoming necessary to invest less inspector time per facility without losing safeguards effectiveness. Continuous unattended radiation and surveillance monitoring systems significantly reduce inspector time in facilities. However, continuous measurement systems produce large safeguards databases and require inspector time for thorough review and analysis. We have developed technology based on neural-network pattern-recognition software to automate the review and analysis of safeguards databases. We are enhancing the overall effectiveness of safeguards evaluations through on-line integration of video digital data, radiation monitoring, and other sensor data. Neural-network pattern-recognition analysis of these integrated safeguards data sets increases evaluation effectiveness by showing trends, discovering anomalies, and highlighting specific activities for detailed review by inspectors.

J. A. Howell, C. W. Baumgart, H. O. Menlove, D. Beddingfield, and C. A. Rodriguez, "Anomaly Detection in an Item-Handling Nuclear Facility Using Pattern Recognition—Progress Report," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-994 (September 1994).

We have developed a prototype anomaly detection application that reviews data collected from continuous unattended monitoring systems. Using neural network pattern recognition, this system distinguishes normal from abnormal material movements in a test laboratory. This progress report describes results to date.

J. A. Howell, H. O. Menlove, C. Rodriguez, D. Beddingfield, C. Baumgart, A. Vasil, and J. E. Brown, "Video Time Radiation Analysis Program (VTRAP)—Requirements and Preliminary Design Document," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-995 (September 1994).

We describe a system for detecting anomalies in an item-handling facility. We describe not only the functions available in our prototype but also the functions required for a future production system and a preliminary design for satisfying those requirements.

S.-T. Hsue, H. O. Menlove, G. E. Bosler, H. R. Dye, G. Walton, J. K. Halbig, and R. Siebelist, "Research Reactor Fork Users Manual," Los Alamos National Laboratory report LA-12666-M (ISPO-355) (November 1993).

This manual describes the design features and operating characteristics of the research reactor fork. The system includes an ion chamber for gross gamma-ray counting, fission chambers for neutron counting, and a collimated high-resolution spectroscopy system for gamma-ray measurements. The neutron and ion chamber measurements are designed to be made underwater in spent-fuel cooling ponds. The neutron and gamma-ray detectors have been designed with high efficiencies to accommodate the relatively low emission rates of neutrons and gamma rays from low-burnup, research-type reactor fuel. This manual presents the design, performance, and test results for the system.

W. J. Huntman and R. J. Caldwell, "The Impact of Changes in DOE Computer Security on Safeguards Systems," *Nucl. Mater. Manage.* XXIII, 47-52 (1994).

Recent changes in the Department of Energy regulations on classified computer security have

introduced a number of significant requirements for automated information systems and networks. These changes are necessary because of changes in computer technology, a reduced level of clearances, and increased personnel access, such as DOE "L" clearances and international inspections, in the facilities. These changes will affect all computer-based systems that process, or are connected to computers that process, classified data. The additional and modified requirements are identified and described. The impact of the requirements on safeguards computer-based systems, such as instruments, database systems, and networks, is reviewed. Some simple examples of typical safeguards systems are discussed with suggestions on how the systems can comply with the requirements.

W. J. Huntman and R. Caldwell, "Independent Validation and Verification of Automated Information Systems in the Department of Energy," for presentation at the 17th National Computer Security Conference, Baltimore, Maryland, October 11-14, 1994. Los Alamos National Laboratory document LA-UR-94-2128.

The Department of Energy (DOE) has established an Independent Validation and Verification (IV&V) program for all classified automated information systems (AIS) operating in compartmented or multi-level modes. The IV&V program was established in DOE Order 5639.6A [1] and described in the manual [2] associated with the Order.

This paper describes the DOE IV&V program, the IV&V process and activities, the expected benefits from an IV&V, and the criteria and methodologies used during an IV&V. The first IV&V under this program was conducted on the Integrated Computing Network (ICN) at Los Alamos National Laboratory and several lessons learned are presented.

The DOE IV&V program is based on the following definitions. An IV&V is defined as the use of expertise from outside an AIS organization to conduct validation and verification studies on a classified AIS. Validation is defined as the process of applying the specialized security test and evaluation procedures, tools, and equipment needed to establish acceptance for joint usage of an AIS by one or more departments or agencies and their contractors. Verification is the process of comparing two levels of an AIS specification for proper correspondence (e.g., security policy model with top-level specifications, top-level specifications with source code, or source code with object code).

S. F. Klosterbuer, J. K. Halbig, W. C. Harker, H. O. Menlove, J. A. Painter, and J. E. Stewart, "Continuous Remote Unattended Monitoring For Safeguards Data Collection Systems" presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994, Los Alamos National Laboratory document LA-UR-94-256.

To meet increased inspection requirements, unattended and remote monitoring systems have been developed and installed in several large facilities to perform safeguards functions. These unattended monitoring systems are based on instruments originally developed for traditional safeguards and the domestic nuclear industry to nondestructively assay nuclear materials. Through specialized measurement procedures, these instruments have been adapted to be unattended monitors. This paper defines the parts of these unattended monitoring systems, describes the systems that have been installed in the field and their status, and discusses future trends for unattended systems.

M. S. Krick, N. Ensslin, D. G. Langner, M. C. Miller, R. Siebelist, J. E. Stewart, R. N. Ceo, P. K. May, and L. L. Collins, Jr., "Active Neutron Multiplicity Analysis and Monte Carlo Calculations," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 494-499 (1994).

Active neutron multiplicity measurements of high-enrichment uranium metal and oxide samples have been made at Los Alamos and Y-12. The data from the measurements of standards at Los Alamos were analyzed to obtain values for neutron multiplication and source-sample coupling. These results are compared to equivalent results obtained from Monte Carlo calculations. An approximate relationship between coupling and multiplication is derived and used to correct doubles rates for multiplication and coupling. The utility of singles counting for uranium samples is also examined.

D. G. Langner, M. S. Krick, and K. E. Kroncke, "A Large Multiplicity Counter for the Measurement of Bulk Plutonium," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 474-479 (1994).

We have considered the problem of designing a thermal neutron counter for the neutron multiplicity measurement of large, high-mass plutonium items. Three neutron multiplicity counters have been built at Los Alamos to date; two are used for in-plant

applications. The third counter is an experimental prototype and is used for research. The sample cavities of these counters can accommodate only relatively small samples. The largest item that can be measured optimally by the largest of these counters is 20 cm wide by 36 cm high. Now that the multiplicity technique has proven to be accurate and timely for the measurement of plutonium-bearing items, several facilities in the DOE complex have identified the need for larger counters. Several sources have identified a counter that could measure items contained in 30-gal. drums as the most desirable. For a multiplicity measurement to be successful, the neutron counter must have a large detection efficiency independent of changes in the neutron energy of the emitted neutrons, a short die-away time, and a uniform response over the sample cavity. These requirements have been achieved in the smaller counters by using large numbers of ^3He tubes placed in concentric rings. This method can be extrapolated to a larger counter but at great expense. We have conducted a design study for a 30-gal. drum counter. The goal of this study is to reduce the number of ^3He tubes required for such a large counter while still maintaining good measurement performance. This paper will report on the results of this study.

S. M. Long, F. Hsue, C. Hoth, R. Fernandez, C. Bjork, and J. Sprinkle, "Design and Fabrication of 55-Gallon Drum Shuffler Standards," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 470-473 (1994).

To analyze waste with varying levels of nuclear material, suitable standards are needed to calibrate analytical instrumentation. At the Los Alamos Plutonium Facility, we have designed and fabricated a single drum standard for a passive-active neutron counter (shuffler). The standard is modified simply by adding or subtracting plutonium or uranium cylinders to adapt to a range of nuclear material. The plutonium or uranium oxide was placed into small cylindrical containers (1-in. diameter by 5-in. long) and diluted with diatomaceous earth. The cylinders were welded closed and removed from the glove box environment without any external contamination. The containers were leak tested and then placed on a segmented gamma scanner to assure homogeneous distribution of the nuclear material. The cylinders are now placed into the drum to achieve the needed ranges for calibration of the instruments.

J. T. Markin and W. D. Stanbro, "Policy and Technical Issues for International Safeguards in Nuclear Weapons States," presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994. Los Alamos National Laboratory document LA-UR-94-184.

The application of international safeguards in nuclear weapons states (NWS) to verify fissile materials declared excess to weapons purposes and cessation of fissile material production for weapons use would create policy and technical issues for the international inspectorate and the NWS. This paper examines options for resolving these issues including modifications in the International Atomic Energy Agency (IAEA) goals and safeguards approaches that would reduce inspection effort (with collateral reduction in inspection effectiveness), modifications in NWS classification laws to allow measurement of selected attributes of sensitive materials or to allow access to classified data by inspectors from selected NWS, offering weapons materials in an unclassified form to accommodate traditional IAEA safeguards, innovations in technology that would reduce resource intensity of inspections, and innovations in technology that would allow verification of weapons materials and facilities while limiting disclosure of sensitive data.

H. O. Menlove, M. S. Krick, D. G. Langner, M. C. Miller, and J. E. Stewart, "Advances In Passive Neutron Instruments For Safeguards Use," presented at the IAEA Symposium on International Safeguards, Vienna, Austria, March 14-18, 1994, Los Alamos National Laboratory document LA-UR-94-164.

Passive neutron and other nondestructive assay techniques have been used extensively by the International Atomic Energy Agency to verify plutonium metal, powder, mixed oxide, pellets, rods, assemblies, scrap, and liquids. Normally, the coincidence counting rate is used to measure the ^{240}Pu -effective mass and gamma-ray spectrometry or mass spectrometry is used to verify the plutonium isotopic ratios. During the past few years, the passive neutron detectors have been installed in plants and operated in the unattended/continuous mode. These radiation data with time continuity have made it possible to use the totals counting rate to monitor the movement of nuclear material. Monte Carlo computer codes have been used to optimize the detector designs for specific applications. The inventory sample counter (INVS-III) has been designed to have a higher efficiency (43%) and a larger uniform counting volume than the original INVS. Data analyses techniques have been developed, including the

"known alpha" and "known multiplication" methods that depend on the sample. For scrap and other impure or poorly characterized samples, we have developed multiplicity counting, initially implemented in the plutonium scrap multiplicity counter. For large waste containers such as 200-L drums, we have developed the add-a-source technique to give accurate corrections for the waste-matrix materials. This paper summarizes recent developments in the design and application of passive neutron assay systems.

H. O. Menlove, L. A. Foster, and J. Baca, "NBC Operation Manual Including the Multi-position Add-A-Source Function," Los Alamos National Laboratory report LA-12737-M (March 1994).

This manual describes the design modifications and operating characteristics of a 200-l-drum neutron coincidence counter. The counter has six shielded banks of ^3He tubes and JSR-11 shift register coincidence electronics. The modified design has a counting efficiency of 19.3%. The neutron counter measures the spontaneous-fission rate from the plutonium, and when this is combined with the plutonium isotopic ratios, we can determine the plutonium mass. The system includes the new multi-position add-a-source (AS) technique that uses a small ^{252}Cf source to determine the drum's matrix perturbation to the plutonium assay. The ^{252}Cf source is measured at three positions on the exterior of the drum to obtain the spatial distribution for the matrix correction. This manual gives the performance and calibration parameters. The matrix corrections by the AS technique are accurate to a few percent for typical applications.

H. O. Menlove, J. K. Halbig, G. E. Bosler, P. M. Rinard, and S. W. O'Rear, Jr., "The Design and Calibration of the Spent-Fuel Neutron Coincidence Counter for Underwater Applications," Los Alamos National Laboratory report LA-12769-MS (May 1994).

A neutron coincidence counter designed to count spent-fuel assemblies under water in storage pools has been designed, fabricated, tested, calibrated, and applied. The detector contains ion chambers for gross gamma-ray counting and high-efficiency neutron detectors for singles and coincidence counting. Lead shielding protects the ^3He neutron detectors from the intense gamma-ray dose. Fast AMPTEK amplifiers improve the neutron to gamma-ray discrimination ratio. A neutron detection efficiency of 14% has been achieved. This report gives details concerning

the operating parameters and the calibration of the system for plutonium-uranium metal mixtures. The measurement results are presented with a comparison to the plutonium determined from reprocessing the fuel.

H. O. Menlove, J. A. Howell, C. A. Rodriguez, G. W. Eccleston, D. Beddingfield, J. E. Smith, and C. W. Baumgart, "Integration of Video and Radiation Analysis Data," *Nucl. Mater. Manage.* XXIII, 834-841 (1994).

We have introduced a new method to integrate spatial (digital video) and time (radiation monitoring) information. This technology is based on pattern recognition by neural networks, provides significant capability to analyze complex data, and has the ability to learn and adapt to changing situations. This technique could significantly reduce the frequency of inspection visits to key facilities without a loss of safeguards effectiveness.

J. F. Metzler, N. R. Zack, and C. D. Jaeger, "Design Considerations for Third-Party Inspection Activities for Storage Facilities," *Nucl. Mater. Manage.* XXIII, 246-250 (1994).

Initiatives by the President and the Secretary of Energy to make available national excess special nuclear materials for third party inspection and verification required special design requirements to be considered for the reconfigured weapons complex storage facilities. The approach that will be taken in the design and operation will permit controlled access to all nuclear materials and related information that would not disclose or lead to disclosure of classified or proprietary information not obligated by treaty or other agreements. This approach would provide the third party inspectors with the information and capability to access designated materials while minimizing impact upon facility operations. These considerations would also give the federal government the flexibility to add new materials to the excess materials category list in the future. This paper will discuss the safeguards and security design impacts and features that are being anticipated for the storage facilities, both for possible new construction and upgrading existing facilities.

M. C. Miller and D. D. Yearwood, "Criticality Study of Various Highly Enriched Uranium Samples Measured in

an Active Well Coincidence Counter," Los Alamos National Laboratory report LA-12837-MS, ISPO No. 365 (September 1994).

A criticality study has been conducted for the measurement of highly enriched uranium (HEU) samples using the Active Well Coincidence Counter (AWCC). Computer calculations were performed to estimate the k_{eff} of large samples inside the AWCC in the form of metal, UF_4 , and UO_2 . The discrete ordinates transport code TWODANT was used for all computations. In performing the study, we varied the AWCC in the following ways: (a) with and without the cadmium sample-cavity liner, (b) with and without the nickel reflector, and (c) with a water-filled sample cavity. Metal samples consisted of right-circular cylinders containing masses of up to 20 kg of uranium (18.6 kg of ^{235}U) with a 12-cm diam. The samples of UF_4 and UO_2 contained up to 10 kg of ^{235}U , had a height-to-diameter ratio of unity, and were modeled as both dry and having a moisture content of up to 40% by weight. The most reactive configuration resulted when we removed the cadmium liner and nickel reflector and flooded the sample cavity with water (case 3). Results of the study indicate a maximum k_{eff} of 0.96 for the water-filled cavity containing a 20-kg uranium-metal cylinder ($h = 9.41$ cm, $d = 12$ cm). Dry samples composed of 10 kg of ^{235}U in the form of UF_4 ($\rho = 6.7$ g/cm³) and UO_2 ($\rho = 110$ g/cm³) resulted in a maximum k_{eff} of 0.64 and 0.71 respectively. Samples of UF_4 and UO_2 , also containing 10 kg of ^{235}U , with 10% moisture by weight resulted in a maximum k_{eff} of 0.81 and 0.83 respectively. *The subcritical limit for a water-flooded chamber without the nickel and cadmium in place is somewhat greater than 20% moisture by weight for a homogeneous fissile-water mixture containing 10 kg of ^{235}U .*

M. C. Miller, E. L. Adams, T. K. Li, and R. B. Strittmatter, "A Feasibility Study for the Application of Radiation Monitoring for International Safeguards at an Atomic Vapor Laser Isotope Separation (AVLIS) Facility," Los Alamos National Laboratory report LA-12813-MS (September 1994).

We have evaluated the feasibility of using radiation monitoring for international safeguards at an Atomic Vapor Laser Isotope Separation (AVLIS) uranium enrichment facility. Techniques employing neutron and gamma-ray detection were investigated and evaluated to determine their applicability for detecting highly enriched uranium. This task is complicated because classified information must not be

revealed in the inspection activity. Within this constraint, we concluded that (1) neutron methods will not be a viable option for measurements at the separator module, (2) gamma-ray measurements at the separator module are possible but cannot be adequately verified, and (3) neutron and gamma-ray approaches are suitable for measurements of feed, product, and tails. If international safeguards are applied at an AVLIS facility, neutron and gamma-ray instruments will need to be designed and optimized.

M. C. Miller, H. O. Menlove, D. H. Beddingfield, T. C. Wenz, and K. Asakura, "Conceptual Design Study of Non-destructive Assay Equipment for the Advanced Thermal Reactor Fuel Fabrication Line," Los Alamos National Laboratory document LA-CP-94-199 (for limited distribution).

A conceptual design study, including Monte Carlo calculations, has been performed of nondestructive assay equipment for the Advanced Thermal Reactor fuel fabrication line at the Plutonium Fuel Production Facility in Tokai, Japan. The equipment will be used by the International Atomic Energy Agency as a part of their safeguards inspection activities. This study addresses details of proposed equipment design including performance, operational mode, and cost. As such, it lays a foundation for the future work involving final design, fabrication, and installation of the nondestructive assay instrumentation for safeguards use.

N. Miura and H. Menlove, "The Use of Curium Neutrons to Verify Plutonium in Spent Fuel and Reprocessing Wastes," Los Alamos National Laboratory report LA-12774-MS (May 1994).

For safeguards verification of spent fuel, leached hulls, and reprocessing wastes, it is necessary to determine the plutonium content in these items. We have evaluated the use of passive neutron multiplicity counting to determine the plutonium content directly and also to measure the $^{240}\text{Pu}/^{244}\text{Cm}$ ratio for the indirect verification of the plutonium. Neutron multiplicity counting of the singles, doubles, and triples neutrons has been evaluated for measuring ^{240}Pu , ^{244}Cm , and ^{252}Cf . We have proposed a method to establish the plutonium to curium ratio using the hybrid k-edge densitometer x-ray fluorescence instrument plus a neutron coincidence counter for the reprocessing dissolver solution. This report presents the concepts, experimental results, and error estimates for typical spent fuel applications.

C. T. Olinger, "Acoustic Resonance Spectroscopy for Safeguards," presented at the ANS 1994 Annual Meeting and the 11th Topical Meeting on the Technology of Fusion Energy, New Orleans, Louisiana, June 19-23, 1994; ANS Trans. 70, 67-68 (1994).

No abstract.

C. T. Olinger, "Acoustic Resonance Spectroscopy in Support of Arms Control and Nonproliferation," for publication in "Arms Control and Nonproliferation Technologies," Los Alamos National Laboratory document LA-UR-94-1504.

No abstract.

C. T. Olinger, Tom L. Burr, and D. R. Vnuk, "Acoustic Resonance Spectroscopy Intrinsic Seals," *Nucl. Mater. Manage.* XXIII, 776-782 (1994).

We have begun to quantify the ability of acoustic resonance spectroscopy (ARS) to detect the removal and replacement of the lid of a simulated special nuclear materials drum. Conceptually, the acoustic spectrum of a container establishes a baseline fingerprint, which we refer to as an intrinsic seal, for the container. Simply removing and replacing the lid changes some of the resonant frequencies because it is impossible to exactly duplicate all of the stress patterns between the lid and container. Preliminary qualitative results suggested that the ARS intrinsic seal could discriminate between cases where a lid has or has not been removed. The present work is directed at quantifying the utility of the ARS intrinsic seal technique, including the technique's sensitivity to "nuisance" effects, such as temperature swings, movement of the container, and placement of the transducers. These early quantitative tests support the potential of the ARS intrinsic seal application, but also reveal a possible sensitivity to nuisance effects that could limit environments or conditions under which the technique is effective.

T. H. Prettyman, R. J. Estep, R. A. Cole, and G. A. Sheppard, "A Maximum-Likelihood Reconstruction Algorithm for Tomographic Gamma-Ray Nondestructive Assay," presented at the 1994 Symposium on Radiation Measurements and Applications, The University of Michigan, Ann Arbor,

Michigan, May 16-19, 1994, Los Alamos National Laboratory document LA-UR-94-1650.

A new tomographic reconstruction algorithm for nondestructive assay with high-resolution gamma-ray spectroscopy (HRGS) is presented. The reconstruction problem is formulated using a maximum-likelihood approach in which the statistical structure of both the gross and continuum measurements used to determine the full-energy response in HRGS is modeled. An accelerated expectation-maximization algorithm is used to determine the optimal solution. The algorithm is applied to safeguards and environmental assays of large samples (for example, 55-gal. drums) in which high continuum levels caused by Compton scattering are routinely encountered. Details of the implementation of the algorithm and a comparative study of the algorithm's performance are presented.

T. H. Prettyman, J. K. Sprinkle, Jr., and G. A. Sheppard, "Performance of an Advanced Lump Correction Algorithm for Gamma-Ray Assays of Plutonium," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 893-896 (1994).

The results of an experimental study to evaluate the performance of an advanced lump correction algorithm for gamma-ray assays of plutonium is presented. The algorithm is applied to correct segmented gamma scanner (SGS) and tomographic gamma scanner (TGS) assays of plutonium samples in 55-gal. drums containing heterogeneous matrices. The relative ability of the SGS and TGS to separate matrix and lump effects is examined, and a technique to detect gross heterogeneity in SGS assays is presented.

M. M. Pickrell and P. K. Kendall, "The Synchronous Active Neutron Detection Assay System," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 452-469 (1994).

We have begun to develop a novel technique for active neutron assay of fissile material in spent nuclear fuel. This approach will exploit the unique operating features of a 14-MeV neutron generator developed by Schlumberger. This generator and a novel detection system will be applied to the direct measurement of the fissile material content in spent fuel in place of the indirect measures used at present.

The technique we are investigating is termed synchronous active neutron detection (SAND). It closely follows a method that has been used routinely in other branches of physics to detect very

small signals in the presence of large backgrounds. Synchronous detection instruments are widely available commercially and are termed "lock-in" amplifiers. We have implemented a digital lock-in amplifier in conjunction with the Schlumberger neutron generator to explore the possibility of synchronous detection with active neutrons. This approach is possible because the Schlumberger system can operate at up to a 50% duty factor, in effect, a square wave of neutron yield.

The results to date are preliminary but quite promising. The system is capable of resolving the fissile material contained in a small fraction of the fuel rods in a cold fuel assembly. It also appears to be quite resilient to background neutron interference. The interrogating neutrons appear to be non-thermal and penetrating. Although a significant amount of work remains to fully explore the relevant physics and optimize the instrument design, the underlying concept appears sound.

M. M. Pickrell and P. K. Kendall, "The Synchronous Active Neutron Detection System for Spent Fuel Assay," presented at the I&EC Special Symposium, American Chemical Society, Atlanta, Georgia, September 19-21, 1994. Los Alamos National Laboratory document LA-UR-94-3135.

We have begun to develop a novel technique for active neutron assay of fissile material in spent nuclear fuel. This approach will exploit the unique operating features of a 14-MeV neutron generator developed by Schlumberger. This generator and a novel detection system will be applied to the direct measurement of the fissile material content in spent fuel in place of the indirect measures used at present.

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in a cold fuel assembly. It also appears to be quite resilient to background neutron interference. The interrogating neutrons appear to be nonthermal and penetrating. Although a significant amount of work remains to fully explore the relevant physics and optimize the instrument design, the underlying concept appears sound.

P. M. Rinard and T. H. Prettyman, "Techniques for Improving Shuffler Assay Results for 55-Gallon Waste Drums," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 1301-1305 (1994).

Accurate assays of the fissile contents in waste drums are needed to ensure the most proper and economical handling and disposal of the waste. An improvement of accuracy will mean fewer drums disposed as transuranic waste when they really contain low-level waste, saving both money and burial sites.

Shufflers are used for assaying waste drums and are very accurate with nonmoderating matrices (such as iron). In the active mode they count delayed neutrons released after fissions are induced by irradiation neutrons from a ^{252}Cf source. However, as the hydrogen density from matrices such as paper or gloves increases, the accuracy can suffer without proper attention. The neutron transport and fission probabilities change with the hydrogen density, causing the neutron count rate to vary with the position of the fissile material within the drum. The magnitude of this variation grows with the hydrogen density.

For many common moderating matrices, a simple hardware addition to reduce the average energy of the irradiating neutrons eliminates this problem. But this has the potential of creating another loss of accuracy by increasing self-shielding. Three other techniques are being investigated that maintain the high average neutron energy. These are based on (a) the variance among detector bank counts, (b) a medium-resolution imaging technique, and (c) neural network analysis of detector bank counts. The present states of all four techniques are summarized and compared.

C. Rodriguez, "Life and Times: The Development of a Digital Video Surveillance System," *Nucl. Mater. Manage.* XXIII, 273-276 (1994).

Over the past few years Los Alamos National Laboratory's Safeguards Systems Group has been working to develop an image-based digital surveillance system designed to provide continuous moni-

toring of nuclear materials in storage or process. The goal of such a system is to provide automated technologies that will ensure the security of the nuclear materials and ultimately reduce the frequency of required physical inventories. This paper discusses the highlights and low-lights we have encountered while designing, developing, and field-testing a digital video surveillance system.

T. E. Sampson and T. A. Kelley, "The FRAM Code: Description and Some Comparisons with MGA," presented at the MGA User's Workshop, Geel, Belgium, October 19-20, 1994. Los Alamos National Laboratory document LA-UR-94-3331.

We will describe the initial development of the FRAM gamma-ray spectrometry code for analyzing plutonium isotopics, discuss its methodology, and present some comparisons with MGA on identical items. We will also present some of the features of a new Windows 3.1-based version (PC/FRAM) and describe some current measurement problems.

G. A. Sheppard and E. C. Piquette, "Point-Source Calibration of a Segmented Gamma-Ray Scanner," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 855-859 (1994).

For a conventional segmented gamma-ray scanner (SGS) in which the sample is rotated continuously within a fixed detector field of view, the data will not support alternatives to the assumption that the gamma-emitting nuclides and the matrix in which they reside are uniformly distributed. This homogeneity assumption permits the geometry of samples and calibration standards to be approximated by that of a nonattenuating line source on the axis of rotation. Other common SGS assumptions are that the detector is perfectly collimated, that its response is flat over its field of view, and that it can be approximated adequately by a line. All of these assumptions have led to a preference for homogeneous calibration standards. Preparation and certification of such calibration standards are usually difficult and expensive. Storage and transportation of SGS standards can be inconvenient or even quite troublesome. We have proposed and tested an alternative method of SGS calibration that only requires a point-source standard. The proposed technique relies on the empirical determination of a normalized two-dimensional detector response and the measurement of the count rate from a point-source standard located at the response apex. With these data, the system's response to a distributed, homogeneous sample can be predicted using numerical integration. Typical

biases measured using a commercially available SGS calibrated with a point source have been less than 2%.

G. A. Sheppard, T. H. Prettyman, and E. C. Piquette, "Accounting for Segment Correlations in Segmented Gamma-Ray Scans," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 882-886 (1994).

In a typical segmented gamma-ray scanner (SGS), the detector's field of view is collimated so that a complete horizontal slice or segment of the desired thickness is visible. Ordinarily, the collimator is not deep enough to exclude gamma rays emitted from sample volumes above and below the segment aligned with the collimator. This can lead to assay biases, particularly for certain radioactive-material distributions. Another consequence of the collimator's low aspect ratio is that segment assays at the top and bottom of the sample are biased low because the detector's field of view is not filled. This effect is ordinarily countered by placing the sample on a low-Z pedestal and scanning one or more segment thicknesses below and above the sample. This takes extra time, however. We have investigated a number of techniques that both account for correlated segments and correct for end effects in SGS assays. Also, we have developed an algorithm that facilitates estimates of assay precision. Six calculation methods have been compared by evaluating the results of thousands of simulated assays for three types of gamma-ray source distribution and ten masses. We will report on these computational studies and their experimental verification.

H. A. Smith, Jr., H. O. Menlove, T. Douglas Reilly, G. E. Bosler, E. A. Hakkila, and G. W. Eccleston, "The Los Alamos Nuclear Safeguards and Nonproliferation Technology Development Program," submitted for presentation at the 9th KAIF/KNS Annual Conference co-sponsored by the Korean Nuclear Society and the Organization of Korean Atomic Energy Awareness, April 6-8, 1994, Seoul, Republic of Korea, Los Alamos National Laboratory document LA-UR-94-887.

For nearly three decades, Los Alamos National Laboratory has developed and implemented nuclear measurement technology and training in support of national and international nuclear safeguards. This paper outlines the major elements of those technologies and highlights some of the latest developments.

J. Smith, "ARGUS TID Database Users' Manual," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-882 (September 1994).

Tamper indicating devices (TID) on containers must be accounted for according to DOE Order 5633.3a.1. A database for tracking container TIDs has been added to the PC-DYMAC material accounting program, part of the ARGUS(Argonne Unified Safeguards) integrated material control and accountability system running at the Argonne National Lab-West (ANL-W) Fuel Manufacturing Facility (FMF). This document contains instructions for using and maintaining this database and shows editing screens and sample reports.

J. Smith and R. Bearse, "ARGUS/PC-DYMAC Portability Issues," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-883 (September 1994).

PC-DYMAC, the core material accounting program for the ARGUS integrated safeguards system, uses a transaction processing model that has survived many conversions to different systems over the last two decades. We examine the portability characteristics of ARGUS software components and the model of ARGUS.

W. D. Stanbro, "Grandfathering and an SNM Production Cutoff," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-714 (June 1994).

The Clinton administration has made an international agreement banning the production of plutonium or highly enriched uranium (HEU) for nuclear explosive purposes or outside of safeguards an important element of its nonproliferation policy. Negotiations on this agreement at the Conference on Disarmament (CD) are expected to begin shortly. It is generally conceded that a major goal of the proposed cutoff agreement is to draw in the nuclear threshold states. These are states with significant nuclear programs that have not adhered to the Nonproliferation Treaty (NPT). Evidently, a cutoff agreement must offer different provisions than the NPT if it is to interest these states. One suggestion that has been featured prominently is to "grandfather" nuclear material produced before entry into force (EIF). This means that material produced before EIF would not be subject to the provisions of the agreement. This paper will discuss various forms such a provision

could take. In particular it will address four issues: the dichotomy between concessions to make the agreement acceptable and legitimization of unsafe-guarded nuclear programs, the potential for adverse interaction with the NPT, the question of what to grandfather, and finally the impact of grandfathering on the verification.

W. D. Stanbro, "Potential International Safeguards on DOE Spent Fuel," presented at the ANS-sponsored DOE Spent Nuclear Fuel—Challenges and Initiatives Conference, Salt Lake City, Utah, December 13-16, 1994. Los Alamos National Laboratory document LA-UR-94-3287.

To demonstrate openness to the world community, the US is placing some nuclear material connected with its weapons program under international inspection. Currently this does not include the large amount of spent fuel at Department of Energy (DOE) facilities. This paper presents some possible scenarios that would require international safeguards of spent fuel at DOE facilities. It also describes the likely activities of such an inspection regime.

J. E. Stewart, C. R. Hatcher, L. L. Pollat, W. C. Harker, S. Abeynaike, S. Tsalas, S. Synetos, M. Swinhoe, S. Baumann, E. Haas, K. Kohl, L. Bevaart, K. Chitumbo, J. King, P. Karasuddhi, and R. Olsen, "Development of an Integrated, Unattended Assay System for LWR-MOX Fuel Pellet Trays," *Nucl. Mater. Manage.* XXIII (Proc. Issue), 842-849 (1994).

Four identical unattended plutonium assay systems have been developed for use at the new light-water-reactor mixed oxide (LWR-MOX) fuel fabrication facility at Hanau, Germany. The systems provide quantitative plutonium verification for all MOX pellet trays entering or leaving a large, intermediate store. Pellet-tray transport and storage systems are highly automated. Data from the "I-Point" (information point) assay systems will be shared by the Euratom and International Atomic Energy Agency (IAEA) Inspectorates.

The I-Point system integrates, for the first time, passive neutron coincidence counting (NCC) with electro-mechanical sensing (EMS) in unattended mode. Also, provisions have been made for adding high-resolution gamma spectroscopy. The system accumulates data for every tray entering or leaving the store between inspector visits. During an inspection,

data are analyzed and compared with operator declarations for the previous inspection period, nominally one month.

Specification of the I-point system resulted from a collaboration between the IAEA, Euratom, Siemens, and Los Alamos. Hardware was developed by Siemens and Los Alamos through a bilateral agreement between the German Federal Ministry of Research and Technology (BMFT) and the US DOE. Siemens also provided the EMS subsystem, including software. Through the USSupport Program to the IAEA, Los Alamos developed the NCC software (NCC COLLECT) and also the software for merging and reviewing the EMS and NCC data (MERGE/REVIEW).

This paper describes the overall I-Point system, but emphasizes the NCC subsystem, along with the NCC COLLECT and MERGE/REVIEW codes. We also summarize comprehensive testing results that define the quality of assay performance.

G. L. Van Ryn and N. R. Zack, "New Department of Energy and Guidance for Cost Effectiveness in Nuclear Materials Control and Accountability Programs," *Nucl. Mater. Manage.* XXIII, 949-954 (1994).

Recent Department of Energy (DOE) initiatives have given Departmental nuclear facilities the opportunity to take more credit for certain existing safeguards and security systems in determining operational program protection requirements. New policies and guidance are coupled with these initiatives to enhance systems performance in a cost-effective and efficient manner as well as to reduce operational costs. The application of these methods and technologies support safety, the reduction of personnel radiation exposure, emergency planning, and inspections by international teams. This discussion will review guidance and policies that support advanced systems and programs to decrease lifetime operational costs without increasing risk.

R. Whiteson, "An Anomaly Detector Applied to a Material Control and Accounting System," *Nucl. Mater. Manage.* XXIII, 318-323 (1994).

Large amounts of safeguards data are automatically gathered and stored by monitoring instruments used

in nuclear chemical processing plants, nuclear material storage facilities, and nuclear fuel fabrication facilities. An integrated safeguards approach requires the ability to identify anomalous activities or states in these data. Anomalies in the data could be indications of error, theft, or diversion of material. The large volume of the data makes analysis and evaluation by human experts very tedious, and the complex and diverse nature of the data makes these tasks difficult to automate. This paper describes our early work in the development of analysis tools to automate the anomaly detection process. Using data from accounting databases, we are modeling the normal behavior of processes. From these models we hope to be able to identify activities or data that deviate from that norm. Such tools would be used to reveal trends, identify errors, and recognize unusual data. Thus the expert's attention can be focused directly on significant phenomena.

R. Whiteson, "The Effectiveness of a Processing Facility Plant Model," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-957 (September 1994).

Large amounts of safeguards data are automatically gathered and stored by monitoring instruments used in nuclear chemical processing plants, nuclear material storage facilities, and nuclear fuel fabrication facilities. An integrated safeguards approach requires the ability to identify errors and anomalies in these data. Anomalies in the data could be indications of error, theft, or diversion of material. The large volume of data makes analysis and evaluation by human experts very tedious, and the complex and diverse nature of the data makes these tasks difficult to automate. We are developing analysis tools to automate the anomaly detection process. Using data from accounting databases, we are modeling the normal behavior of processes. From these models we hope to be able to identify activities or data that deviate from that norm. Such tools would be used to reveal trends, identify errors, and recognize unusual data. Thus the expert's attention can be focussed directly on significant phenomena.

D. D. Wilkey and D. W. Crawford, "Graded Safeguards: Determination of Attractiveness Levels for Special Nuclear Materials," *Nucl. Mater. Manage.* XXIII, 1059-1062 (1994).

The DOE graded safeguards approach—as described in DOE Order 5633.3A, Control and Accountability of Nuclear Materials, and its guide—requires the determination of category levels of nuclear material locations to establish protection requirements for

these locations. A critical parameter related to category determination is knowledge of the attractiveness level of the nuclear material with respect to use in a nuclear explosive device. DOE Order 5633.3A and its guide provide the policy basis for determining the attractiveness level of various forms and types of special nuclear material (SNM); however, these requirements and guidance are necessarily general and sometimes based on arbitrary criteria. Currently, there are large quantities of nuclear material on inventory within the DOE that need attractiveness determinations to ensure appropriate protection controls. Specific forms of these materials include materials in matrices requiring special processing, irradiated SNM that does not meet criteria for self-protecting, low concentration SNM, SNM as numerous small items, and bulk non-portable SNM items. This paper discusses the technical basis for applying material concentration limits for solids and liquids that can influence the various factors and criteria affecting the attractiveness level of SNM. Holdup and rollup considerations for determining category levels will be discussed as well.

D. D. Wilkey, W. T. Wood, and C. D. Guenther, "Long-Term Plutonium Storage: Design Concepts," *Nucl. Mater. Manage.* XXIII, 251-255 (1994).

An important part of the Department of Energy (DOE) Weapons Complex Reconfiguration (WCR) Program is the development of facilities for long-term storage of plutonium. The WCR design goals are to provide storage for metals, oxides, pits, and fuel-grade plutonium, including material being held as part of the Strategic Reserve and excess material. Major activities associated with plutonium storage are storing the plutonium inventory, material handling and storage support, shipping and receiving, and surveillance of material in storage for both safety evaluations and safeguards and security. A variety of methods for plutonium storage have been used, both within the DOE weapons complex and by external organizations. This paper discusses the advantages and disadvantages of proposed storage concepts based upon functional criteria. The concepts discussed include floor wells, vertical and horizontal sleeves, warehouse storage on vertical racks, and modular storage units. Issues/ factors considered in determining a preferred design include operational efficiency, maintenance and repair, environmental impact, radiation and criticality safety, safeguards and security, heat removal, waste minimization, international inspection requirements, and construction and operational costs.

M. A. Yates, W. D. Stanbro, and J. Sanborn, "Options for Verification of an SNM Production Cutoff," *Nucl. Mater. Manage.* XXIII, 510-515 (1994).

As part of a recent nonproliferation initiative, President Clinton has called for an international regime to ensure that plutonium and highly enriched uranium are not produced for nuclear explosives. Although the obligations of non-nuclear weapons states under full-scope safeguards would not change under this regime, nuclear weapons states could be obliged to accept more intensive inspections at their facilities. This paper will describe several options that could be employed to verify that facilities in weapons states are not being used to produce special nuclear material for weapons. The scope of these regimes could range from very broad, encompassing many of a state's facilities, to more narrowly focused ones concerned only with those facilities that produce direct use materials (enrichment and reprocessing plants). The advantages and disadvantages of each regime will be discussed.

N. R. Zack, W. J. Huntman, P. M. Rinard, C. D. Jaeger, and J. F. Metzler, "Improved Safeguards and Security of a National Resource," presented at the ANS 1994 Annual Meeting and the 11th Topical Meeting on the Technology of Fusion Energy, New Orleans, Louisiana, June 19-23, 1994; *ANS Trans.* 70, 67 (1994).

Initiatives by the President and the Secretary of Energy to reduce the quantity of nuclear materials in the nation's strategic reserve are increasing the quantity of materials to be held in long-term storage until a final disposition option is imposed. These excess materials will be available for third-party inspection and verification to provide assurance that declared materials are not being diverted for weapons production. These protection systems must be capable of detecting unauthorized attempts to gain access to or control of the materials and information. Facility designs can incorporate new concepts and techniques that will minimize impact on operations and significantly reduce lifetime operational and infrastructure costs from safeguards and security requirements. The safeguards and security systems will be coupled with other facility systems such as safety, emergency preparedness, and process control to enhance public, worker, and environmental protection; protect nuclear materials, related information, and technology; and mitigate or prevent accidents and sabotage involving the nuclear materials. This paper will discuss the application of proven, state-of-the-art safeguards, physical security, computer/information security, and materials assay systems that can be

combined to provide a cost-effective, efficient means for monitoring and protecting these materials.

N. R. Zack and E. J. Kirk, "Weapons Dismantlement Issues in Independent Ukraine," *Nucl. Mater. Manage.* XXIII, 510-515 (1994).

The American Association for the Advancement of Science sponsored a seminar during September 1993, in Kiev, Ukraine, entitled "Toward a Nuclear Free Future—Barriers and Problems." It brought together Ukrainians, Belarusians, and Americans to discuss the legal, political, safeguards and security, economic, and technical dimensions of nuclear weapons dismantlement and destruction. US representatives initiated discussions on legal and treaty requirements and constraints, safeguards and security issues surrounding dismantlement, storage and disposition of nuclear materials, warhead transportation, and economic considerations. Ukrainians gave presentations on arguments for and against the Ukraine keeping nuclear weapons, Ukrainian Parliament non-approval of START I, alternative strategies for dismantling silos and launchers, and economic and security implications of nuclear weapons removal from the Ukraine. Participants from Belarus discussed proliferation and control regime issues. This paper will highlight and detail the issues, concerns, and possible impacts of the Ukraine's dismantlement of its nuclear weapons.

A. Zardecki, "Multiobjective Resource Allocation Problem for Safeguards," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-490 (March 1994).

RAOPS—Resource Allocation Optimization Program for Safeguards—is extended to a multiobjective return function having the detection probability and expected detection time as criteria. The expected detection time is included as a constraint, based on the well-known Avenhaus model of the optimum number of inventory periods. Examples of computation are provided.

A. Zardecki, "Fuzzy Risk Analyzer," Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-489 (March 1994).

Fuzzy Risk Analyzer, a general purpose code for fuzzy risk analysis, allows one to evaluate the risk associated with a composite system on the basis of the risk estimate of individual components. After outlining elements of the risk analysis, we discuss

the notions of fuzzy arithmetic, followed by the specific features of the code implementation. An illustrative example of risk evaluation is provided.

A. Zardecki, "Fuzzy Control for Forecasting and Pattern Recognition in a Time Series," Third IEEE International Conference on Fuzzy Systems, Orlando Florida, June 26-July 2, 1994. Los Alamos National Laboratory document LA-UR-93-4271.

No abstract

A. Zardecki, "Analysis of Inventory Difference Using Fuzzy Controllers," *Nucl. Mater. Manage.* XXIII, 304-308 (1994).

In fuzzy control, expert knowledge is encoded in the form of fuzzy rules, which describe recommended actions for different classes of situations represented by fuzzy sets. The concept of a fuzzy controller is applied to the forecasting problem in a time series, specifically, to forecasting and detecting anomalies in inventory differences. This paper reviews the basic notion underlying the fuzzy control systems and provides examples of application. The well-known material-unaccounted-for diffusion plant data of Jaech are analyzed using both feedforward neural networks and fuzzy controllers. By forming a difference between the forecasted and observed signals, an efficient method to detect small signals in background noise is implemented.

A. Zardecki, "Fuzzy Controllers in Nuclear Material Accounting," presented at the First International Workshop

on Fuzzy Logic and Intelligent Technologies in Nuclear Science," Mol, Belgium, September 19-21, 1994; in *Fuzzy Logic and Intelligent Technologies in Nuclear Science*, Da Ruan, Pierre D'hondt, and Paul Govaerts, Eds. (World Scientific, New Jersey, 1994), pp. 183-187.

No abstract.

A. Zardecki, "Application of the Fuzzy Risk Analyzer to Facility Data" Los Alamos National Laboratory, Safeguards Systems Group report NIS-7/94-985 (September 1994).

Fuzzy Risk Analyzer, a general purpose code for fuzzy risk analysis, is applied to analysis of the risk factor at two selected DOE facilities. In addition, the code predicts the critical path and allows one to set up an if-then simulation.

A. Zardecki and J. T. Markin, "RAOPS: Resource Allocation Optimization Program for Safeguards," presented at the 28th Annual IEEE International Carnahan Conference on Security Technology, Albuquerque, New Mexico, October 12-14, 1994. Los Alamos National Laboratory document LA-UR-94-1936.

RAOPS (Resource Allocation Optimization Program for Safeguards) is extended to a multiobjective return function having the detection probability and expected detection time as criteria. The expected detection time is included as a constraint, based on the well-known Avenhaus model of the optimum number of inventory periods. Examples of computation are provided.

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