UNCLASSIFIED

EGG-ACTP--10144

DE92 018092

**The Nuclear Materials Control
Technology Briefing Book**

J. K. Hartwell and S. J. Fernandez

March 1992

EG&G Idaho, Inc.
Idaho Fall, ID 83415

Prepared for the
U.S. Department of Energy
Idaho Operations Office
under DOE Contract
No. DE-AC07-76ID01570

UNCLASSIFIED

MASTER

DISTRIBUTION RESTRICTED TO U.S. ONLY

ABSTRACT

As national and international interests in nuclear arms control and non-proliferation of nuclear weapons intensify, it becomes ever more important that contributors be aware of the technologies available for the measurement and control of the nuclear materials important to nuclear weapons development. This briefing book presents concise, nontechnical summaries of various special nuclear material (SNM) and tritium production monitoring technologies applicable to the control of nuclear materials and their production. Since the International Atomic Energy Agency (IAEA) operates a multinational, on-site-inspector-based safeguards program in support of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), many (but not all) of the technologies reported in this document are in routine use or under development for IAEA safeguards.

ACKNOWLEDGMENTS

This briefing book contains the contributions of scientists throughout the DOE laboratory complex. Constructive comments on a predecessor to this work were received from contributors at Savannah River, Los Alamos National Laboratory, Livermore National Laboratory, Oak Ridge National Laboratory, the Idaho National Engineering Laboratory, and Argonne National Laboratory, in addition to the staff of DP-5.1 of the DOE's Office of Arms Control (OAC). The authors would particularly like to thank Ray Warner (PNL), Jim Tape (LANL), Denny Mangan (SNL), John Googin (Y-12), and Al Boni (SRS) for significant contributions to this work. The support of OAC DP-5.1 is gratefully acknowledged. Ms. Corrine Casey (INEL) contributed to the initial version of this work.

CONTENTS

ABSTRACT	iii
ACRONYMS	vi
1.0 INTRODUCTION	1
1.1 Material Accountancy Procedures	1
1.2 Assumed Nuclear Materials Control Scenario	2
1.3 Briefing Book Organization	5
2.0 MEASUREMENT TECHNOLOGIES	9
2.1 Technologies applicable to both Pu and Uranium measurement	11
2.2 Technologies primarily applicable to Pu measurement	58
2.3 Technologies primarily applicable to uranium measurement	90
2.4 Technologies primarily applicable to tritium measurement	110
2.5 Technologies for measurement of other important attributes	124
3.0 CONTAINMENT AND SURVEILLANCE DEVICES	170

TABLES

1.0 Master technology index	6
2.1 Technologies applicable to both Pu and U measurements	13
2.2 Technologies primarily applicable to Pu measurement	58
2.3 Technologies primarily applicable to U measurement	91
2.4 Technologies primarily applicable to tritium measurement	111
2.5 Technologies for the measurement of other important attributes	125
3.0 Containment and surveillance devices	172

ACRONYMS

ACDA	The US Arms Control and Disarmament Agency
AIMS	Authenticated item monitoring system
ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
BWR	Boiling Water Reactor, a common type of power reactor using slightly enriched uranium fuel and light water moderation.
C&S	Containment and surveillance, a term used for seals, cameras, and system monitors emplaced for safeguards purposes.
CANDU	A power reactor of Canadian design. CANDUs use natural uranium fuel, heavy water moderation, and are routinely reloaded while at power.
CEA	The French Commissariat à l'Energie Atomique
DOE	The US Department of Energy
DP	Defense Programs
DYMAC	Dynamic material and control
EURATOM	European Atomic Energy Community
FBR	Fast breeder reactor, a reactor design that relies on fast neutron fluence, and is generally liquid sodium cooled.
Ge	Germanium, a semiconductor material used to fabricate gamma-ray detectors.
HEU	Highly enriched uranium (>20% ²³⁵ U)
HLNCC	High level neutron coincidence counter
IAEA	International Atomic Energy Agency
ICPP	Idaho Chemical Processing Plant, a spent fuel reprocessing plant at the INEL.
INEL	Idaho National Engineering Laboratory
INMM	Institute of Nuclear Materials Management
JAERI	Japanese Atomic Energy Research Institute
JRC	Joint Research Centre
KfK	the German Kernforschungszenrum Karlsruhe
LANL	Los Alamos National Laboratory
LASCAR	Large SCALE Reprocessing plants. An IAEA program to develop safeguards techniques for large scale spent fuel reprocessing facilities. A goal of LASCAR is to improve safeguards while saving on inspector resources.
LED	Light-emitting diode
LEU	Low-enriched uranium (<20% ²³⁵ U)
LIS	Laser isotope separation facility
LLNL	Lawrence Livermore National Laboratory
MBA	Material balance area
MIVS	Modular integrated video system
MOX	Mixed oxide fuel, nuclear reactor fuel fabricated from a mixture of plutonium and uranium oxides.
NaI(Tl)	Thallium activated sodium iodide, a type of gamma-ray detector
NBL	the US DOE's New Brunswick Laboratory

NIST	National Institute of Standards and Technology
NOAA	National Oceanic & Atmospheric Administration
NPT	the Treaty on the Non-Proliferation of Nuclear Weapons
NRTA	Near real-time accountancy
NTM	National technical means
OAC	the US DOE's Office of Arms Control
ORNL	Oak Ridge National Laboratory
OSI	On-site inspection
OSIA	the US On-Site Inspection Agency
PMCA	Portable multichannel analyzer
PNL	Pacific Northwest Laboratory
POTAS	US Program for Technical Assistance to IAEA Safeguards
Pu	Plutonium
PWR	Pressurized Water Reactor, the most common type of nuclear power reactor. PWRs use slightly enriched uranium fuel and light water moderation.
RBMK	A nuclear power reactor of Soviet design. RBMKs are light water cooled, graphite moderated reactors that are routinely reloaded while at power.
RECOVER	Remote continual verification system
RPI	Rensselaer Polytechnic Institute
RSL	the US DOE's Remote Sensing Laboratory
SNL	Sandia National Laboratory
SNM	Special Nuclear Material
SRS	Savannah River Site
TASTEX	Tokai Advanced Safeguards Technology Exercise, a joint IAEA-US-Japanese-French project to address a series of development tasks related to spent fuel reprocessing plant safeguards.
U	Uranium
VVER	A pressurized water reactor (PWR) of Soviet design
XRF	X-ray fluorescence
Y-12	A plant area at the DOE's Oak Ridge complex

THE NUCLEAR MATERIALS CONTROL TECHNOLOGY BRIEFING BOOK

1.0 INTRODUCTION

As national and international interests in nuclear arms control and non-proliferation of nuclear weapons intensify, it becomes ever more important that contributors be aware of the technologies available for the measurement and control of the nuclear materials important to nuclear weapons development. This briefing book presents concise, nontechnical summaries of various special nuclear material (SNM) and tritium production monitoring technologies applicable to the control of nuclear materials and their production. Since the International Atomic Energy Agency (IAEA) operates a multinational, on-site-inspector-based safeguards program in support of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), many (but not all) of the technologies reported in this document are in routine use or under development for IAEA safeguards.

1.1 Material Accountancy Procedures

The science of nuclear material safeguards, as practiced both internationally and domestically, is concerned with a rigorous accounting of the SNM inventory of facilities within a country in order to detect the diversion of SNM to prohibited uses. Material accountancy procedures that balance the measured or otherwise verified SNM inventory of a facility, or more correctly, of subdivisions [termed material balance areas (MBA's)] within a facility, with the recorded transfers into and out of the MBA's are the primary technique of SNM safeguards. In some facilities in which the SNM is contained in countable packages (fuel assemblies at a reactor, for example), the inventory can be expected to balance exactly, and any difference between the item count and the "book" inventory is a significant defect. However, in "bulk" handling facilities such as reprocessing plants and enrichment facilities in which the SNM is handled in solution, solid, or even gaseous form, inventories must be established by measurement of volumes, weights, and concentrations. Since these measurements are subject to random and systematic errors, the book and measured inventories will seldom agree exactly, and inventory differences

(ID's) can occur. Highly developed mathematical procedures are available to evaluate ID's in order to detect possible SNM diversion and to plan inspection activities in order to provide adequate inventory verification. These techniques, since they are beyond the scope of this work are not reviewed herein. However, the measurement technologies for quantification of nuclear material quantities are reviewed in Section 2.0 (and subsections) of this work. It is important to realize that the more accurately and precisely SNM inventories can be measured, the smaller the allowable ID and thus the lower the potential diversion.

Safeguarding of item count facilities, such as reactors and spent fuel storage facilities, is highly dependent on inspector-emplaced seals and tags, and on surveillance technologies. These "containment and surveillance" (C&S) technologies are reviewed in Section 3.0 of this briefing book. Seals and tags developed for more demanding applications have been reviewed elsewhere and are not included in this briefing book.

In bulk handling facilities material accountancy procedures incorporate methods of weighing, measuring tank volumes, and system flow rates in addition to techniques for measuring SNM content and concentration. The routine process control instruments often used to provide these measurements are not reviewed in this document; however, certain technologies for these measurements that have been specifically investigated for SNM safeguards purposes are summarized. Similarly, security devices for perimeter monitoring are not reviewed unless they are safeguards specific; however, portal monitoring devices developed for SNM detection are reviewed.

1.2 Assumed Nuclear Materials Control Scenario

To provide a comprehensive materials control scenario to guide the selection of technologies for this briefing book, a reference scenario of a treaty-negotiated limitation on the production of special nuclear materials and tritium (a so-called production "cutoff") was selected. The control of nuclear weapons through limitations on the production of these nuclear materials has been a recurrent arms control proposal. Choice of this scenario in no way implies its acceptability or desirability; but rather, provides a

comprehensive reference scenario against which technology needs may be assessed.

The assumed treaty scenario that guided the selection of technologies for this briefing book is outlined below. The scenario includes the features common to most proposals for SNM production cutoff as an arms control measure.

The assumed components of an SNM production cutoff are:

- Plutonium (Pu) production for weapons purposes would be prohibited.

Defense reactors and facilities solely dedicated to production of Pu for the weapons stockpile would be shutdown and their layaway status verified by a combination of periodic inspections, seals and monitors, and NTM. Reprocessing of power reactor fuel and a civilian Pu recycle program would be allowed but monitored.

- Production of highly enriched uranium (HEU) for weapons purposes would also be prohibited; however, uranium enrichment would continue.

Production of low enriched uranium (LEU) for civilian power production would continue under safeguards. Production of HEU (>20% ^{235}U) for naval propulsion and space, research, and tritium production reactor consumption would be allowed within some mutually negotiated annual production limit. The treaty partner would verify the quantity of HEU produced.

- Production of tritium to replenish the stockpile would continue, but would be limited to less than some negotiated annual maximum.

Production assets devoted to tritium production would be declared and portal monitoring, perhaps coupled with on-site inspection of reactor and separation facilities would be employed to ensure that prohibited SNM production did not occur, and to verify compliance with the negotiated production "cap".

- All civilian nuclear facilities would be placed under SNM safeguards.

These safeguards would be similar to the "full scope" safeguards applied by the International Atomic Energy Agency (IAEA) in non-weapons States party to the NPT. These safeguards may be applied bilaterally, multilaterally, or by the IAEA.

Under this reference scenario, technologies would be primarily directed to verifying the shutdown status of prohibited facilities, verifying the enrichment of the product (and possibly, the tails) from uranium enrichment facilities, identification of suspect sites, and safeguarding of SNM in the treaty partner's civilian nuclear cycle to preclude diversion of significant quantities to weapons production. Additional technologies would be required to verify that tritium production assets were not converted to clandestine fissile material production, and to ensure that the negotiated maximum annual tritium production was not exceeded.

Requirements for verification of the reference treaty scenario are:

1. Verify that declared prohibited facilities are shutdown and remain unused.
2. Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
3. Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.
4. Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.
5. Verify that prohibited tritium production does not occur in civilian power reactors.
6. Identify suspected SNM and/or tritium handling facilities for challenge inspections.

These tasks provide the framework for the control of nuclear materials for

either arms control or nuclear non-proliferation. Each technology summarized in this briefing book references the applicable verification requirement(s).

1.3 Briefing Book Organization

A few words about the organization of this document are in order. The technology summaries are brief and are relatively nontechnical. Active researchers who might want more technical details should use the vast technical document base that exists in nuclear materials safeguards and controls. Three recommended review works, published by the US Nuclear Regulatory Commission, are: *Handbook of Nuclear Safeguards Measurement Methods*, D. R. Rogers, Editor, NUREG/CR-2078 (1983); *Active Nondestructive Assay of Nuclear Material, Principles and Applications* by T. Gozani, NUREG/CR-0602 (1981); and, *Passive Nondestructive Assay of Nuclear Materials*, D. Reilly et al, Editors, NUREG/CR-5550 (1991). The research for this document was conducted in 1989 and 1990 and published in draft form in May of 1990. While some of the information has been updated for this version, much of the status information reflects 1989 to 1990 data.

Two separate categories are presented: Measurement Technologies, and Containment and Surveillance (C&S) Technologies. The Measurement Technologies section (Section 2.0 and subsections) catalogs techniques for detecting and quantifying the nuclear materials. C&S devices, in the second major section (Section 3.0), include portal monitors, surveillance systems, seals, and monitoring systems designed to indicate the real-time status of these devices.

Each major section begins with a brief description of the organization of that document section, followed by an index table that lists the technologies summarized. The Measurement Technologies section is subdivided by the elemental species to be measured. Each subsection begins with a brief summary of the "state-of-the-art" relative to the subject technologies. The subsection introductions also include an index table that cross references the summarized technologies to applicable facilities and verification regimes.

Table 1.0 presents the master index to the summarized technologies.

TABLE 1.0 MASTER TECHNOLOGY INDEX

	<u>Page</u>
2.0 MEASUREMENT TECHNOLOGIES	9
2.1 Technologies applicable to both Pu and Uranium Measurement	11
Stabilized assay meter (SAM II)	14
Gamma-ray spectrometers	16
Portable gamma-ray spectrometers	18
Segmented gamma scanner (SGS)	20
Portable hold-up monitor	22
Passive neutron detectors	24
Slab detector	26
Passive neutron coincidence counters	28
"Random driver" SNM analysis devices	30
Sub-threshold SNM analysis devices	32
"Shuffler" SNM analysis systems	34
Combined passive and active neutron assay systems (Differential die-away)	36
Photofission assay	38
X-ray absorption edge densitometer	40
X-ray fluorometer (XRF)	42
Hybrid solution assay system	44
Electrochemical titration	46
Controlled-potential coulometry	48
Spectrophotometric analyses	50
Mass spectrometry	52
Laser-induced breakdown spectroscopy (LIBS)	54
Lead slowing-down time spectrometer	56
2.2 Technologies primarily applicable to Pu measurement	58
Pu isotopic ratios by gamma-ray spectroscopy	62
Neutron briefcase	64
High level neutron coincidence counter (HLNCC)	66
Inventory sample coincidence counter (INVS)	68
Plutonium neutron coincidence collar	70
Fast breeder reactor (FBR) assembly counter	72
Compact K-edge densitometer	74
Internal-source densitometry (ISD)	76
Alpha spectrometry	78
On-line alpha monitor	80
Advanced automated controlled-potential-coulometric analyzer (AACPC)	82
Advanced automated Pu titration system (AAPIS)	84
Automated high precision spectrophotometric Pu assay	86
Bulk plutonium assay calorimeter	88
2.3 Technologies primarily applicable to Uranium measurement (including U enrichment)	90
Gravimetric analysis	92
Uranium neutron coincidence collar (UNCL)	94
Nuclear solution assay system	96
U enrichment by gamma-ray spectrometry	98
Transportable quadrupole mass spectrometer	100

In-line gas-phase enrichment monitor	102
Stationary area neutron monitoring system	104
UF ₆ flow meters	106
Transportable load-cell-based system (LCBS)	108
2.4 Technologies primarily applicable to Tritium measurement	110
Non-destructive lithium screening	112
Liquid scintillation counting	114
Internal ionization chambers	116
Mass spectrometry	118
Calorimetry	120
Liquid tritium monitor	122
2.5 Technologies for the measurement of other important attributes	124
Cerenkov glow viewing devices	128
Fork detector	130
Python device	132
Cf-252 source-driven noise analysis system	134
Isotope correlation technique (ICT)	136
Track etch power monitor	138
He-3 reactor power monitor	140
Reactor power monitoring by antineutrino detection	142
Unattended gamma-ray spectrometers	144
Near real-time accountancy (NRTA) or Dynamic materials and control (DYNAMIC) systems	146
Load cell monitors	148
Electromanometer	150
Process monitoring systems	152
Mobile measurement systems	154
Retrospective confirmation of environmental trends (RECET)	156
Passive cryogenic sampler	158
Particle inlet mass spectrometry (PIMS)	160
Remote ambient sulfur detector	162
Aerial radiation measurement systems	164
Airborne thermal imaging	166
NASA/NOAA Landsat thermatic mapper	168
3.0 CONTAINMENT AND SURVEILLANCE DEVICES	170
Hand-held SNM monitors	174
Gamma-ray-based SNM portal monitors	176
Neutron-based SNM portal monitors	178
CORONA radiation detection system	180
Be(γ ,n) core discharge monitor	182
Laser surveillance system	184
Crane motion monitors	186
Wireless alarm transmission of container handling (WATCH)	188
Authenticated item monitoring system (AIMS)	190
Tamper indicating container and the authenticated item monitoring system	192
Surveillance cameras (Film)	194
Modular integrated video system (MIVS)	196
Portable surveillance unit (PSU)	198
Digital image processing for materials control	200
Cobra seal system (fiber optic system)	202
Adhesive seals	204

Cup-and-wire seal (E-seal)	206
Shrink-tubing seal	208
VACOSS electronic sealing system	210
Ultrasonic seals	212
Remote continual verification system (RECOVER)	214

2.0 MEASUREMENT TECHNOLOGIES

Technologies for measurement of SNM and tritium are presented in five subsections:

- 2.1. Technologies for measurement of both Pu and U
- 2.2. Technologies primarily applicable to Pu measurements
- 2.3 Technologies primarily applicable to U measurements
(including determination of U enrichment)
- 2.4 Technologies primarily applicable to Tritium measurements
- 2.5 Technologies for measurement of other important attributes
(including spent fuel burn up, thermal signatures, etc.)

Each subsection introduction includes a brief evaluation of the verification requirements dictated by the reference scenario, and of the "state-of-the-art" relating to measurement of the referenced material. Each introduction also includes a cross reference table relating each summarized technology to the primary facilities in which it is useful, and indicating the applicable verification regime. The verification regimes noted on the cross reference tables indicate if the technology is primarily useful to an on-site inspector for measurements during an OSI (On-site inspection); primarily applicable for central laboratory analysis of samples obtained by on-site inspectors or other cooperative means (Lab confirmation); could be considered as an installed surveillance monitor (Installed monitor); or, is a technology used to monitor the environment for effluents indicative of SNM-handling activities to aid in establishing prohibited operation and/or suspect site identification (Environmental mon).

Each cross reference table also catalogs the level of technology maturity. Mature, presently implemented technologies are given an "M"; technologies under development and judged to be short term (within 2-3 years availability) were given a "D"; while longer term and/or more conceptual technologies are

identified with a "C". The "maturity" ranking relates to the measurement technology per se and is inconsiderate of any required hardening or tailoring required for the verification task.

2.1 TECHNOLOGIES APPLICABLE TO BOTH PU AND URANIUM MEASUREMENT

All of the technologies cataloged in this section are direct measurement technologies primarily applicable either to use by an on-site inspector during inspection of civilian nuclear facilities, or for the subsequent laboratory analysis of samples obtained either by an inspector or through a cooperative sample exchange. Certain of these technologies could be adapted for use as unattended installed monitoring systems to augment or possibly supplant an inspector presence or in some cases to verify the shutdown status of inactive facilities. Table 2.1 provides a list of the summarized technologies and a cross reference to their primary facilities and regimes

Since both plutonium (Pu) and uranium (U) are radioactive elements, certain measurement technologies, that have been highly developed for general radioactive material measurements, are equally applicable to Pu and U determinations. An example of such a technology is gamma-ray spectrometry (the determination of concentrations of unknown radioactive materials by measuring the energy and number of the gamma rays they emit). Gamma-ray spectrometric techniques are highly developed for SNM measurements both in the laboratory and in the field. These measurements are a mainstay of IAEA safeguards inspectors.

Both ^{240}Pu and ^{238}U emit neutrons that can be detected and used to indicate their presence. While somewhat less useful for U determination than for Pu (since the ^{240}Pu neutron emission rate is higher per gram than the ^{238}U emission rate, and highly enriched uranium has only a small neutron emission) devices have been configured that exploit this neutron emission. Most notable are the passive neutron coincidence detectors. Several versions of these devices are commercially available.

Both Pu and U have isotopes that fission when bombarded by neutrons. It is this fissile property that makes these isotopes of interest, and has been exploited in a number of mature and fielded instruments for measurement of SNM. Some of the more frequently used devices are the random drivers and the shufflers described herein. Again, these technologies are mature and many devices are commercially available.

Included in the compilations of this section are technologies that do not exploit the inherent radioactive nature of SNM nor the fissile nature of the selected isotopes, but rather rely on other element specific characteristics. These include "classical" chemical techniques that are applicable in one mode or another to nearly all elemental analyses, but have been specifically tailored to SNM measurements. Notable examples are the laboratory techniques of electrochemical titration, mass spectrometry, and coulometry that provide the most accurate analyses of Pu and U solution concentrations that are available today. Another notable class of element-specific technologies are those that rely on X-ray interrogation and response -- the absorption edge and fluorometric techniques. Highly accurate and mature devices that use these measurement techniques have been developed.

TABLE 2.1 Technologies applicable to both Pu and U measurements

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Stabilized assay meter (SAMII)	*		*	*	*		*				M
Gamma-ray spectrometers	*	*	*	*	*		*	*	*		M
Portable gamma-ray spectrometers	*	*	*	*	*		*				M
Segmented gamma scanner (SGS)	*	*	*	*	*		*	*			M
Portable hold-up monitor			*	*	*		*				M
Passive neutron detectors	*	*	*	*	*		*	*	*		M
Slab detector			*	*	*		*		*		M
Passive neutron coincidence counter	*		*	*	*		*	*			M
"Random driver" SNM analysis devices	*		*	*	*		*	*			M
Sub-threshold SNM analysis device	*	*	*				*	*			M
Shuffler SNM analysis systems			*	*	*		*	*			M
Combined active and passive neutron assay systems (differential dieaway)			*	*	*		*	*			M
Photofission assay			*	*	*		*	*			M
X-ray absorption edge densitometer			*	*	*		*	*	*		M
X-ray fluorometer (XRF)			*	*	*		*	*	*		M
Hybrid solution assay system			*				*	*			M
Electrochemical titration			*	*	*			*			M
Controlled-potential coulometry			*	*	*			*			M
Spectrophotometric analysis			*	*	*			*			M
Mass spectrometry			*	*	*			*			M
Laser-induced breakdown spectroscopy (LIBS)			*	*	*			*	*		D
Lead slowing-down time spectrometer	*	*	*					*			D

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurement of SNM content in containers and pipes.

TECHNOLOGY

Stabilized assay meter (SAM II)

DESCRIPTION

The SAM II is a simple rugged device that can determine the content of plutonium and uranium compounds in casks and containers by counting characteristic gamma rays. Counts are accumulated in an energy window, allowing selection of the characteristic gamma-ray energy. All required electronics are in a simple portable package with an attached detector probe. SAM II's are generally used with NaI(Tl) gamma-ray detectors; however, some applications using Ge detectors and even neutron counters have been developed.

BACKGROUND

SAM II's are a routine field instrument in a number of disciplines (safeguards, health physics, etc.).

STATUS

Routine use for more than a decade.

AVAILABILITY

Commercially available.

COMMENTS

SAM II's are being replaced in most applications by the PMCA or with more specific instruments.

STABILIZED ASSAY METER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurements during on-site inspections and/or laboratory analysis of samples obtained during OSI's.

TECHNOLOGY

Gamma-ray spectrometers

DESCRIPTION

Gamma-ray spectrometers when properly designed and calibrated can accurately determine the type and quantity of SNM in a sample by detecting the gamma rays emitted by the sample. Gamma-ray spectrometers consist of a detector along with electronics required to process detector pulses and store a spectrum of number of counts versus gamma-ray energy. From these spectra and the known measurement conditions, the gamma-ray-emitting isotopes in the sample can be identified and quantified. Gamma-ray spectrometer detectors are overwhelmingly of two types -- Sodium Iodide (NaI) scintillation detectors and solid state germanium (or less commonly silicon) detectors. Sodium iodide detectors are rugged and efficient devices but limited in their ability to resolve closely spaced energy lines. Solid state germanium (Ge) detectors are generally less rugged and require cooling to liquid nitrogen temperature during use; however, they are excellent at resolving closely spaced peaks and consequently are more widely used.

BACKGROUND

Gamma-ray spectrometry has been a base technology of radiation measurements for 40 years.

STATUS

Widely used in industry.

AVAILABILITY

Commercially available.

COMMENTS

Ge gamma detector

Gamma-ray source

GAMMA-RAY SPECTROMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection of SNM handling facilities.

TECHNOLOGY

Portable gamma-ray spectrometers

DESCRIPTION

Gamma-ray spectroscopy is routinely used to measure the concentration of certain radioactive species in a variety of samples. Portable, "hand-held" systems incorporating "intelligent" battery-powered 4096 channel multichannel analyzers, and small high resolution Ge detectors are available. Spectra are usually recorded on minicassettes and later read out to a host computer. User programs can be included that guide inspection efforts and perform calculations.

BACKGROUND

A portable mini-multichannel analyzer (PMCA) was developed by LANL.

STATUS

Extensive successful field tests were conducted by the IAEA, and the PMCA was adopted as a routine IAEA field instrument. In 1991, the IAEA had more than 90 units for inspector use.

AVAILABILITY

Commercially available.

COMMENTS

For some applications the PMCA could benefit from installation of a pulser-based calibration system. An INEL pulser-based calibration system has been designed for this device. Other modifications might be required for a specific verification requirement.

PORTABLE GAMMA-RAY SPECTROMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Quantification of SNM content in waste containers.

TECHNOLOGY

Segmented gamma scanner (SGS)

DESCRIPTION

The SGS uses gamma-ray spectrometry to determine the plutonium or uranium content of closed containers. The SGS incorporates a turntable that rotates the sample container in front of a germanium gamma-ray detector. The detector views a horizontal slice of the sample through a lead collimator. After a preset counting interval, the sample turntable raises automatically to expose a new segment of the sample to the detector view and a new count initiated. This technique of sample rotation and segmented scanning, along with an implemented transmission source, allows for correction of the effects of the variable density of the container contents on the gamma-rays of interest. These devices are generally computer controlled. Segmented gamma scanners are available for containers from 1 gallon (3.78 l) to 55 gallon (200 l) drums. They are generally used to quantify the Pu or U content of low density waste, since their accuracy suffers at high container packing densities.

BACKGROUND

Developed by LANL for the measurement of SNM in waste containers.

STATUS

Widely used.

AVAILABILITY

Commercially available.

COMMENTS

SEGMENTED GAMMA SCANNER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection of fabrication, reprocessing, and/or Pu recycle facilities.

TECHNOLOGY

Portable hold-up monitor

DESCRIPTION

"Hold-up" is the term for SNM in a facility that is not recovered during normal plant operations, but is instead deposited in ventilation ducts, pipes, tank heels, etc.. In facilities handling large amounts of SNM these inventories can be large. The compact hold-up monitor is a gamma-ray spectrometric device incorporating a compact, collimated gamma-ray detector (both NaI and Ge detectors are used); a portable multichannel analyzer; a portable IBM personal computer; and special software. In use this equipment is mounted on a cart and the detector pointed at the vent or duct to be measured. A spectrum is accumulated and analyzed by computer.

BACKGROUND

Gamma-ray spectrometers have been used for years for hold-up measurements; however, this device is more portable and compact

STATUS

Prototypes have been assembled and tested. A prototype is in field testing at Y-12. Technology transfer is in progress.

AVAILABILITY

Presently available.

COMMENTS

PORTABLE HOLD-UP MONITOR

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused. Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection and portal monitoring to detect SNM.

TECHNOLOGY

Passive neutron detectors

DESCRIPTION

Pu-240 and ^{238}U emit neutrons as they decay. Neutron detectors allow inspectors to confirm the presence of SNM in closed containers and pipes, estimate the total content, and estimate the degree of enrichment of uranium in enrichment facility piping. A number of detector configurations are available, ranging from small handheld units (SNAP) to large "slab" detectors for room or portal monitoring. Simple counting electronics can be configured to provide rugged monitoring devices.

BACKGROUND

A convenient and portable unit, the Shielded Neutron Assay Probe (SNAP), has been developed at LANL. The SNAP unit is generally being replaced by a compact neutron coincidence monitor (that uses the HLNCC electronics) in IAEA inspector use.

STATUS

Many neutron counters are commercially available. Both SNAP and slab detectors were used extensively to map uranium holdup in the Oak Ridge K-29 enrichment facility to support decontamination and decommissioning of the K-25 Site.

AVAILABILITY

Presently available.

COMMENTS

Neither ^{239}Pu or ^{235}U are significant neutron emitters. Consequently, highly enriched uranium is not efficiently detected by neutron counting. Pu detection is via neutrons from ^{240}Pu [or from (α, n) reactions].

Electronics

Shielded neutron
assay probe

SNM container

PASSIVE NEUTRON COUNTING

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused. Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Attribute monitoring of containers, waste barrels, and even rooms to detect Pu and U.

TECHNOLOGY

Slab detector

DESCRIPTION

The Slab detector is a large area neutron detector which uses proportional counters to detect neutrons emitted by U and Pu isotopes during spontaneous fission. The detector measures 50cm X 60cm X 15cm (20in X 24in X 6in) and is useful for estimating equipment hold up, monitoring waste drums for the presence of Pu or a room for changes in the SNM content.

BACKGROUND

The slab detector was designed by LANL.

STATUS

Both SNAP and slab detectors were used extensively to map uranium holdup in the Oak Ridge K-29 enrichment facility to support decontamination and decommissioning of the K-25 Site.

AVAILABILITY

Commercially available.

COMMENTS

Generally provides "yes-no" monitoring with little or no quantification.

Process Tanks

SLAB DETECTOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection measurements of SNM content of samples in containers and/or laboratory analysis of cooperatively-obtained samples.

TECHNOLOGY

Passive neutron coincidence counters

DESCRIPTION

Pu-240 and ^{238}U decay in part by spontaneously fissioning. These devices measure the concentration of these isotopes, and thus indirectly the total SNM content, of samples by detecting neutrons generated by these fissions. To discriminate between fission events and background these devices require that two or more neutrons be detected in coincidence. Passive neutron coincidence counters have been built in a variety of shapes and sizes for different applications. These units can be highly accurate.

BACKGROUND

Measurement devices using this principle have been used for decades. Many specific instruments have been developed at LANL.

STATUS

Certain of these devices, notably the High Level Neutron Coincidence Counter (HLNCC), are in routine use by the IAEA. A wide variety of "heads" are available for the HLNCC electronics, including ones for canisters, birdcages, pin trays, Pu nitrate bottles, and fuel assemblies.

AVAILABILITY

Some models are commercially available.

COMMENTS

Good sensitivity can only be obtained if the detectors effectively surround the sample. Determination of the total SNM requires that the percentage of ^{240}Pu and/or ^{238}U in the SNM be known, and these devices are less sensitive to U than Pu. Many similar devices use coincident gamma-rays as the fission indicator.

PASSIVE NEUTRON COINCIDENCE COUNTER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurement of SNM content of samples in containers.

TECHNOLOGY

"Random driver" SNM analysis devices

DESCRIPTION

Instruments called "random drivers" can provide accurate measurement of the amount of SNM in containers. A neutron source emitting neutrons one at a time (randomly) interrogates a sample and induces fissions in the contained SNM. The number of induced fissions, and thus the SNM content is determined by counting neutrons (or, less frequently, gamma-rays) and requiring the coincident detection of two or more. Since fissioning SNM emits multiple neutrons (and gamma-rays) simultaneously this coincidence requirement discriminates against the interrogation source background and allows accurate determination of low concentrations of SNM. Specific instruments are available for fuel rods and containers ranging from tuna fish can size to 55 gallon (200 l) drums.

BACKGROUND

Certain specific instruments have been developed by several DOE laboratories. Additional devices have been commercially developed.

STATUS

Devices of this type, notably the Active Well Coincidence Counter (AWCC), are in field use by IAEA safeguards inspectors.

AVAILABILITY

Commercially available.

COMMENTS

Good sensitivity requires that the detectors effectively surround the sample.

RANDOM DRIVER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurement of SNM content of samples in containers.

TECHNOLOGY

Sub-threshold SNM analysis devices

DESCRIPTION

Sub-threshold SNM analysis devices are instruments some what similar to the random drivers; however, discrimination of fission-generated versus source neutrons is accomplished by interrogation with neutrons that are lower in energy than the detection threshold of the neutron detectors. These devices generally use photoneutron sources, such as ^{124}Sb -Be sources that generate 24 keV neutrons. The fast neutrons liberated during the induced fissions are detected using ^3He neutron tubes that are insensitive to the low energy neutrons from the source. This technique eliminates the need for coincidence detection circuitry and provides an instrument somewhat less sensitive to gamma-ray interferences than a random driver.

BACKGROUND

Certain specific instruments have been developed by several DOE laboratories. Most of the sub-threshold devices developed are for monitoring the fissile content of spent fuel. ORNL has developed a system for determining the fissile material in casks of leached Zr "hulls" from reprocessing dissolvers.

STATUS

Developed and implemented

AVAILABILITY

Commercially available.

COMMENTS

The required photoneutron sources can be a significant dose rate hazard, and have relatively short half lives, so frequent source replacement is required.

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurement of SNM content of samples in containers.

TECHNOLOGY

"Shuffler" SNM analysis systems

DESCRIPTION

Shuffler devices depend on the rapid movement of a neutron source from an irradiation position from whence neutrons enter the sample and cause fissions to a shielded position where the source neutrons can not reach sensitive neutron detectors surrounding the sample. When the neutron source has been "shuffled" to the shielded position, the neutron detectors count neutrons emitted from the sample. Since some of the fission neutrons are delayed in time from the fission event, shufflers allow accurate determination of the SNM content of the sample. Shufflers have been designed in a variety of shapes and sizes for the assay of a wide variety of samples. They can measure either U or Pu fissile content. These devices are most often computer controlled.

BACKGROUND

The shuffler system was developed at LANL and in routine use since 1974. Specific devices are at the Idaho Chemical Processing Plant (INEL) and the Savannah River Site (SRS) among others.

STATUS

Well developed and widely used.

AVAILABILITY

Commercially available.

COMMENTS

SHUFFLER DEVICE

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Quantification of SNM in waste drums and containers.

TECHNOLOGY

Combined passive and active neutron assay systems (Differential die-away)

DESCRIPTION

These systems incorporate a set of neutron detectors, a measurement chamber, and a pulsed neutron generator. An initial measurement of the passive neutron counts from spontaneous fission of ^{240}Pu and ^{238}U is made. The sample is then irradiated with neutrons with a time varying energy spectrum. Neutrons emitted by induced fissions are measured. The unit is designed to exhibit significantly different relative neutron lifetimes in the measurement chamber and in the detector. When SNM-bearing samples are introduced into the measurement chamber, their contribution modifies the neutron lifetime (die-away time) of the system. Correlation of the difference in die-away time to SNM content is via standards. The differential die-away time method allows determination of the effects both of the SNM and of the effect from non-SNM matrix materials in the interrogated waste material thus enabling some correction for interferences.

BACKGROUND

Developed at LANL. The first system was installed at Oak Ridge in 1982. Second generation systems have been installed and tested at the INEL, Hanford, and SRS.

STATUS:

Developed, tested, and documented.

AVAILABILITY:

Presently available.

COMMENTS:

For applications in which the waste material contains little hydrogen, modified systems (with ^3He detectors) might enhance the detection of shielded SNM.

DIFFERENTIAL DIE AWAY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Determination of the SNM content of large containers.

TECHNOLOGY

Photofission assay

DESCRIPTION

When SNM is bombarded by gamma-rays with energies above about 6 MeV, the SNM may fission. This has been exploited in a few devices that use linear accelerators to produce an intense high energy gamma-ray beam that irradiates a target. The neutrons and/or gamma-rays emitted by the fissioning SNM are counted to measure the contained quantity. Since photon bombardment can stimulate neutron emission [via (γ, n) reactions] from non-SNM materials, and for operational simplicity, counting is usually delayed from the interrogation pulse, and delayed neutrons and/or gamma-rays are counted (sometimes with a coincidence requirement). This technique is most appropriate for large samples that might preclude effective probing with less penetrating radiations. These devices have been configured on trucks for transportable use.

BACKGROUND

First applications were in about 1970. A device based on this principle is in use for verification measurements at Pantex.

STATUS

Well understood and developed. LANL has demonstrated sufficient differences in the resultant gamma-ray spectra to allow determination of $^{235}\text{U}/^{238}\text{U}$ ratios.

AVAILABILITY

Presently available.

COMMENTS

PHOTOFISSION ASSAY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Measurement of Pu and U content of reprocessing facility streams during on-site inspections.

TECHNOLOGY

X-ray absorption edge densitometer

DESCRIPTION

X-ray absorption edge densitometers measure the concentration of Pu or U solutions by determining the percentage transmission of selected gamma- or x- rays through the solution. The gamma- or x-ray energies are selected to bracket an element-specific absorption band (the K- or L-edge); thus ensuring selectivity for either Pu or U. Plutonium concentration from about 5 g/l to about 400 g/l can be analyzed to 1% precision or better by a properly designed instrument. Total concentrations are determined. No sample preparation time is required, and the measurements may be made in a short time, in fact; several versions of this instrument have been developed for on-line or at-line measurements. These densitometers are rugged, transportable, self-calibrating devices and may use either radioactive sources or electronic tubes to generate the required interrogating rays.

BACKGROUND

X-ray absorption edge densitometers as a safeguards measurement system were developed at LANL, evaluated at SRS and NBL in the US, and as part of the IAEA's TASTEX program.

STATUS

These instruments are accepted as excellent devices for on-line or rapid determination of Pu or U concentrations.

AVAILABILITY

Some models are commercially available.

COMMENTS

Depending on the method of implementation, some moderate effects due to differential absorption in matrix materials such as water and nitric acid can affect the measurement accuracy somewhat.

X-RAY ABSORPTION EDGE DENSITOMETRY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections and/or installed monitors at spent fuel reprocessing facilities.

TECHNOLOGY

X-ray fluorometer (XRF)

DESCRIPTION

Fluorescence of certain materials under a "black light" is a commonly known phenomenon. In an analogous fashion, certain elements, including Pu and U, emit x-radiation when excited by specific incident radiations. X-ray fluorometers determine elemental concentrations by detecting these fluorescence x-rays. X-ray fluorometers can be used on line or off line for measurement of pure or mixed U or Pu over a wide range of concentrations. Accuracies of better than 0.5% have been attained. This instrument does not distinguish between isotopes of the elements detected, but gives the total elemental concentration.

BACKGROUND

X-ray fluorometers have been used in analytical chemistry for a wide variety of elements for several decades. Applications for SNM measurements were developed at Lawrence Livermore National Laboratory.

STATUS

An on-line system was established at Idaho Chemical Processing Plant (INEL) and tested with satisfactory results. Fluorometers adapted for a specific verification environment may require development.

AVAILABILITY

Presently available.

COMMENTS

X-RAY FLUOROMETRY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Rapid measurement of Pu and U content of samples obtained during on-site inspections.

TECHNOLOGY

Hybrid solution assay system

DESCRIPTION

The hybrid solution assay system uses both K-edge absorption densitometry and X-ray fluorescence to analyze a solution sample simultaneously for both Pu and U. Uranium is measured by K-edge absorption, while Pu is measured by X-ray fluorescence (or *vice versa*, depending on the relative concentrations). The instrument uses an x-ray tube as the required x-ray source and employs separate high-resolution Ge gamma-ray detectors for the fluorescence and the transmission measurement. The device is capable of accurate measurements on solutions that are highly contaminated by fission products; consequently, when equipped with remote handling systems, these instruments are excellent devices for analysis of the input solutions in spent fuel reprocessing facilities.

BACKGROUND

The hybrid solution assay system was developed by KfK in Germany.

STATUS

Developed and implemented

AVAILABILITY

Presently available.

COMMENTS

This unit can also determine the Thorium (Th) content of mixed U-Th solutions.

HYBRID SOLUTION ASSAY SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Electrochemical titration

DESCRIPTION

Electrochemical titrations are standard laboratory methods for the measurement of elemental concentrations. A carefully prepared solution sample is analyzed by addition of a measured quantity of a reacting reagent. The "endpoint" of the reaction is indicated electrochemically by a change in the potential at an indicating electrode immersed in the solution. The quantity of reactant required to react completely with the unknown is a measure of the unknown concentration. Titrations of this type that take advantage of the various valence states of plutonium, are the most common method of highly precise analysis of plutonium. A procedure of this type could be applied to Pu accountability samples obtained by an inspector and shipped to a laboratory.

BACKGROUND

These techniques commonly are the basis for shipper-receiver analyses within the US DOE complex.

STATUS

Well developed techniques. An advanced automated Pu titration system is under development at LANL. Recently, an in-line voltametric method for measuring Pu and U has been developed and tested at the Dounreay plant in the UK.

AVAILABILITY

Commercially available. The components required are common devices in analytical laboratories.

COMMENTS

ELECTROCHEMICAL TITRATION

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained on-site or through cooperative exchanges.

TECHNOLOGY

Controlled-potential coulometry

DESCRIPTION

Controlled-potential coulometry is an electrochemical laboratory measurement that determines the total amount of current required to complete an electrochemical reaction. Exacting control of the electrical potential makes the technique specific for either uranium or plutonium. By use of standards, it is then possible to measure concentrations very accurately. These instruments can give high precision measurements of small amounts of U and Pu. A coulometer has been developed which will work automatically under the direction of a computer, thus making the instrument more versatile.

BACKGROUND

Controlled-potential coulometry is routinely used in analytical chemistry for a variety of analyses. Pu assay techniques were highly developed by the DOE's New Brunswick Laboratory (NBL).

STATUS

Controlled potential coulometers are capable of highly precise measurements when operated by a trained electrochemist. An in-line coulometer for Pu and U in flowing streams has been developed.

AVAILABILITY

Presently available. The equipment required to configure controlled potential coulometers is commercially available.

COMMENTS

CONTROLLED POTENTIAL COULOMETRY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Spectrophotometric analyses

DESCRIPTION

These laboratory measurements exploit the fact that specific compounds of elements absorb light at specific wavelengths. An instrument called a spectrophotometer is used to measure the attenuation of a light beam of selected wavelength through a carefully prepared solution sample. The degree of attenuation can be related through the analysis of standards to the concentration of the element in the sample solution. Methods are available for both Pu and U.

BACKGROUND

Among the oldest of analytical techniques.

STATUS

An automated spectrophotometer for the analysis of Pu is under development at LANL.

AVAILABILITY

Commercially available.

COMMENTS

Through the use of fiber optics and chemical sensors, spectrophotometric measurements can be made on- or at-line.

Sample solution
absorbs selected wavelengths

SPECTROPHOTOMETRIC ANALYSIS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Mass spectrometry

DESCRIPTION

Mass spectrometry is a laboratory measurement in which a carefully prepared sample is ionized and subjected to an electromagnetic field such that ions are separated by their charge-to-mass ratio and measured. Mass spectrometry is widely used to establish the isotopic ratios of Pu, to determine uranium enrichment, and to determine tritium. It is a highly precise and accurate technique and is the yardstick against which all other isotopic ratio measurements are compared. By the addition of certain standards, a technique known as isotopic dilution mass spectrometry can yield very precise results on total concentration.

BACKGROUND

A standard laboratory technique for decades. A technique that combined absorption of a 1- to 2-microgram sample of Pu-bearing solution onto an ion exchange resin bead with subsequent mass spectrometric analysis was developed and successfully evaluated under the IAEA's TASTEX program to enhance reprocessing plant safeguards.

STATUS

Well developed.

AVAILABILITY

Presently available.

COMMENTS

MASS SPECTROSCOPY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at spent fuel reprocessing facilities and/or laboratory analysis of samples secured by on-site inspectors.

TECHNOLOGY

Laser-induced breakdown spectroscopy (LIBS)

DESCRIPTION

Laser-induced breakdown spectroscopy is one method of analyzing the U and Pu content of materials. It is a form of atomic emission spectroscopy in which samples are vaporized and excited by laser light and the element-specific emissions from the de-excitation of the atoms are detected and quantified. LIBS requires only optical access to the material to be analyzed. A focused, pulsed, laser produces a plasma from micro quantities of the material to be analyzed. The plasma de-excites with a spark emission that is focused on the input of a spectrophotometer that separates the incident light by wavelength and quantifies the signal.

BACKGROUND

Applications of the technique to U and Pu are under development at LANL. Since the technique is unaffected by some chemical and radiological conditions that interfere with other methods, LIBS is being considered for on-line monitoring of spent fuel reprocessing input solutions.

STATUS

Laboratory development is underway.

AVAILABILITY

Mid term (3 to 5 years)

COMMENTS

The requirement for only optical access, coupled with the potential ability to provide accurate concentrations for U and Pu simultaneously makes this an attractive technique.

LASER INDUCED BREAKDOWN SPECTROSCOPY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at spent fuel reprocessing facilities and/or spent fuel storage facilities.

TECHNOLOGY

Lead Slowing-Down Time Spectrometer

DESCRIPTION

The lead slowing-down time spectrometer provides a unique capability to assay both the ^{239}Pu and the ^{235}U content of spent fuel rods. This can be an important measurement for the input of a spent fuel reprocessing facility, since without such measurements the only accurate measurement of plant input is made after fuel rod dissolution. A lead slowing-down time spectrometer exploits the fact that if a short pulse of mono-energetic neutrons is introduced into a large stack of lead, the neutron energy is modified by scattering in such a way that the neutron energy is a function of time since the pulse. If an SNM-bearing sample is inserted into the lead stack, the neutron interaction rate, and thus the time variation of the neutron counting rate in an imbedded detector is a function of the concentration of each SNM isotope, and the energy dependent neutron fission cross section for that isotope. Since the energy dependence of the fission cross sections for all isotopes of interest varies in different fashions, isotope discrimination is possible. Since the only required counts are total neutron counts, detectors can be chosen that are insensitive to the high gamma radiation from the spent fuel bundles. The neutron pulse is generally provided by a 14-MeV neutron generator. A lead slowing-down time spectrometer will generally weigh about 50 to 100 tonnes.

BACKGROUND

The lead slowing-down time spectrometer has been under development at Rensselaer Polytechnic Institute (RPI) for the past 20 years. One such device was able to measure both ^{239}Pu and ^{235}U in a mixed-oxide (MOX) fuel rod to $\pm 5\%$.

STATUS

While development is advanced, no devices have been fielded for spent fuel safeguards measurements.

AVAILABILITY

Presently available

COMMENTS

Neutron counting rates are generally low; consequently, long (~30 min.) measurement times are common. Resonance self-shielding, the presence of strong moderators, and sample nonuniformity can be sources of error in these measurements.

LEAD SLOWING-DOWN TIME SPECTROMETER

2.2 TECHNOLOGIES PRIMARILY APPLICABLE TO PU MEASUREMENT

Many countries conduct a civilian Pu recycle program, reprocessing spent reactor fuel and recycling the recovered U and Pu into power reactors, while the USA does not. Although the Pu recovered from the power cycle is generally less attractive than Pu manufactured for weapons purposes, verification of the throughput of Pu recycle programs would be required. Power reactor Pu would have to be safeguarded to preclude either direct use in specially designed weapons or diversion to clandestine isotopic separation facilities. Pu recovered from breeder reactor blankets is highly attractive for weapons use. On-load refuelable reactors, such as the Soviet RBMK or the Canadian CANDU design, could be operated in a weapons-grade Pu production mode with less loss in electrical power production efficiency than could the PWRs and BWRs that are the mainstays of the US power program.

Verification of the Pu throughput of a Pu recycle program is primarily concentrated at the reprocessing facilities. The IAEA requires continuous inspector presence at even small reprocessing plants in order to provide adequate safeguards. The IAEA is investigating technologies and methods that might decrease the required inspector commitment at these plants. A significant inspector presence might be supplanted or augmented by unattended installed monitors specifically developed and tailored for use at reprocessing facilities.

Most of the devices cataloged in this section use base technologies previously discussed in section 2.1 (Technologies applicable to both Pu and U measurements); however, the devices cataloged herein have been specifically tailored to the measurement of Pu. For example, the high level neutron coincidence counter (HLNCC) uses the method of passive neutron coincidence counting that was previously discussed; however, the HLNCC has been specifically configured for quantification of the Pu content of containers.

With few exceptions, the measurement technologies for Pu are well developed, and mature technologies. The technology base for direct measurement of Pu in solution or solid form is substantial. However, most methods for the determination of the Pu content of irradiated reactor fuels (or irradiated

blankets in breeder reactors) are indirect, relying on the determination of burn up or fission product ratios. Thus, spent reactor fuels are primarily safeguarded by containment and surveillance of fuel storage facilities.

Table 2.2 catalogs the measurement technologies presented in this section and provides a cross reference to facilities and regimes in which they are most useful.

TABLE 2.2 Technologies primarily applicable to Pu measurement

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Pu isotopic ratios by gamma-ray spectroscopy			*		*		*	*			M
Neutron briefcase	*	*	*		*		*	*			M
High level neutron coincidence counter (HLNCC)			*		*		*	*			M
Inventory sample coincidence counter (INVS)			*		*		*	*			M
Plutonium neutron coincidence collar	*		*		*		*				M
Fast breeder reactor assembly counter	*		*		*		*				M
Compact K-edge densitometer			*				*				M
Internal-source densitometry (ISD)			*				*				D
Alpha spectrometry			*		*		*	*			M
On-line alpha monitor			*				*	*	*		M
Automated advanced controlled-potential coulometric analyzer			*				*	*			D
Advanced automated Pu titration system (AAPTIS)			*		*			*			D
Automated high precision spectrophotometric Pu assay			*		*			*	*		D
Bulk plutonium assay calorimeter			*		*			*			M

THIS PAGE INTENTIONALLY LEFT BLANK

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at fuel reprocessing facilities, or laboratory analysis of cooperatively-obtained samples.

TECHNOLOGY

Pu isotopic ratios by gamma-ray spectroscopy

DESCRIPTION

High resolution gamma-ray spectrometers using solid state germanium detectors can determine the percentage of most isotopes of plutonium in a sample. While each isotope (except ^{242}Pu) emits useful and characteristic gamma rays, these are in some cases very closely spaced; however, careful work with specialized equipment and software packages can yield accurate results for isotopic ratios. This can be an important measurement for an on-site inspector. It can, for example, establish the percentage of ^{240}Pu required for accurate passive neutron assay. Special calculational techniques, based on the enrichment meter principle, can under some conditions determine isotopic ratios, U/Pu ratios, and U and Pu mass fractions in mixed oxide (MOX) fuels.

BACKGROUND

Several systems, for both domestic and international use have been implemented by researchers from various DOE laboratories, notably LLNL, Mound, and LANL.

STATUS

Systems are in routine use.

AVAILABILITY

Presently available.

COMMENTS

A technique, known as isotope dilution gamma-ray spectroscopy, can determine the total Pu concentration of a solution by analysis of spiked and unspiked separated Pu fractions. This technique is applicable to input accountability tanks.

PU ISOTOPIC RATIOS BY GAMMA-RAY SPECTROSCOPY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Identify suspected SNM and/or tritium handling facilities for challenge inspection.

VERIFICATION REGIME

Cooperative challenge inspection of casks, railroad cars, or trucks.

TECHNOLOGY

Neutron briefcase

DESCRIPTION

The neutron briefcase is a compact, high efficiency neutron detector housed in a briefcase. The purpose of the neutron briefcase is to verify the presence of plutonium at distances up to several meters. It can serve as a temporary neutron portal monitor. The neutron detectors are large, lightweight 5-cm diameter, 25-cm active length ^3He proportional counters. Accumulated data are stored in an internal memory for later analysis.

BACKGROUND**STATUS**

Accepted technology.

AVAILABILITY

Presently available.

COMMENTS

Since ^{238}U also emits neutrons during decay, the neutron briefcase can detect uranium that is not highly enriched; however, a larger quantity of U would be required for adequate detection relative to Pu. A similar briefcase system is available that detects gamma-rays.

Neutron briefcase

NEUTRON BRIEFCASE

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection of spent fuel reprocessing facilities and fabrication facilities handling plutonium.

TECHNOLOGY

High level neutron coincidence counter (HLNCC)

DESCRIPTION

Pu-240 decays in part by spontaneously fissioning emitting 2 to 3 neutrons simultaneously. The HLNCC is a transportable device that accurately measures the quantity of ^{240}Pu , and thus, indirectly the amount of Pu, in a sample by counting the coincident neutrons emitted during spontaneous fission decay. The HLNCC is equipped with special electronics that enable it to function properly even at the high neutron counting rates generated by samples containing several kilograms of Pu. One detector configuration is a hexagonal well that can accommodate sealed cans. Additional "heads" are available to measure a variety of different sample configurations (including fuel assemblies) using the same electronics.

BACKGROUND

The HLNCC was developed at LANL and is a routine IAEA inspector instrument.

STATUS

Mature technology.

AVAILABILITY

Presently available.

COMMENTS

Good sensitivity can only be obtained if the detectors effectively surround the sample. Determination of the total Pu quantity requires that the percentage of ^{240}Pu in the sample be known.

HIGH LEVEL NEUTRON COINCIDENCE COUNTER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection at spent fuel reprocessing facilities and MOX fuel fabrication plants.

TECHNOLOGY

Inventory sample coincidence counter (INVS)

DESCRIPTION

The INVS is a passive neutron coincidence counter specifically designed to accurately verify the plutonium content of small samples of plutonium product. The INVS detector incorporates a small cavity (2 cm in diameter) that will accommodate the plastic-bag-wrapped plastic vials routinely used to obtain product samples. Surrounding the detector cavity are 16 ^3He neutron proportional counters that detect neutrons emitted during spontaneous fission of ^{240}Pu . The coincidence detection electronics are those of the high level neutron coincidence counter (HLNCC). Since the sample is small, self multiplication effects are minimized and assay uncertainties of less than 1% are possible. The INVS can be housed in a single carrying case making it an attractive OSI instrument.

BACKGROUND

The INVS was developed by LANL and is a routine IAEA instrument.

STATUS

Field experience with an early version of the INVS indicated a possible problem in sample placement reproducibility. LANL has now developed an improved design.

AVAILABILITY

The INVS is commercially available.

COMMENTS

Accurate assay for total Pu requires that the ^{240}Pu isotopic content be known. LANL has commenced development of a system coupling the INVS with gamma-ray spectrometric determination of the Pu isotopic ratios.

INVENTORY SAMPLE COINCIDENCE COUNTER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection at mixed oxide (MOX) fuel fabrication facilities and MOX-fueled reactors.

TECHNOLOGY

Plutonium neutron coincidence collar

DESCRIPTION

The plutonium neutron coincidence collar is a passive neutron coincidence detector configured in a collar that can be placed around unirradiated MOX fuel assemblies in order to measure their Pu content. The coincident neutrons originating from spontaneous fission of ^{240}Pu are measured to determine the effective ^{240}Pu mass. Sleeves of polyethylene and cadmium can be used to tailor the detector characteristics for a particular type of fuel element. The system electronics are those of the high level neutron coincidence counter (HLNCC).

BACKGROUND

The plutonium neutron coincidence collar was developed in 1982 at LANL.

STATUS

Authorized for IAEA inspector use.

AVAILABILITY

These devices are commercially available from a number of suppliers.

COMMENTS

PLUTONIUM NEUTRON COINCIDENCE COLLAR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at fast breeder power reactors to confirm fresh fuel input.

TECHNOLOGY

Fast breeder reactor (FBR) assembly counter

DESCRIPTION

These devices are a special type of random driver. A set of neutron detectors are designed to fit as a collar on FBR reactor fuel assemblies. The collar is designed with a neutron moderating and reflecting material that, when in place, reflects the neutrons from spontaneous fission of ^{240}Pu back into the assembly as interrogating neutrons. By measuring the multiplication factor due to these interrogating neutrons, the amount of ^{239}Pu (and ^{235}U) in the assembly can be determined. These units can also be tailored to measure plutonium content in large samples. The device is compact and transportable.

BACKGROUND

These devices were originally developed at LANL.

STATUS

The collars are transportable and are approved for IAEA inspector use.

AVAILABILITY

Commercially available.

COMMENTS

FBR ASSEMBLY COUNTER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Rapid measurement of Pu content of samples obtained during on-site inspections at spent fuel reprocessing facilities.

TECHNOLOGY

Compact K-edge densitometer

DESCRIPTION

The compact K-edge densitometer is a portable device designed to measure the concentration of Pu in solutions by determining the percentage transmission of selected gamma-rays through the solution. The unit includes a sample holding fixture that can be inserted into a standard glove box, a portable Ge gamma-ray detector, a set of sources that bracket the Pu K-edge at about 122 keV, and a portable multichannel analyzer (PMCA). The PMCA is programmed to lead the user through the analysis steps and perform the data analysis. This is a very accurate and convenient instrument for on-site inspector use.

BACKGROUND

The compact K-edge densitometer was developed at LANL.

STATUS

Approved for IAEA inspector use.

AVAILABILITY

Presently available.

COMMENTS

COMPACT K-EDGE DENSITOMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection at spent fuel reprocessing facilities.

TECHNOLOGY

Internal-source densitometry (ISD)

DESCRIPTION

The technique of X-ray absorption edge densitometry is well established for the measurement of Pu concentrations in solutions; however, these techniques require an external source of interrogating x-rays. ISD is a novel method of determining the Pu concentration of a solution using the natural radiation emitted by the Pu. The 129 keV gamma-ray of ^{239}Pu and the 111 keV x-ray from both ^{239}Pu and ^{241}Pu bracket the K x-ray absorption edge of Pu; consequently, for a fixed sample thickness, the ratio of the 111/129 keV peak intensities is a sensitive function of Pu concentration. When the sample is very thick, the 111/129 ratio at a given concentration approaches a limit. Thus the ratio can be used directly to measure the concentration of solution in bottles and tanks without drawing samples. The technique is applicable only to relatively pure Pu solutions such as the reprocessing plant Pu product stream.

BACKGROUND

This technique is being developed at LANL.

STATUS

Development continues.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

A second ISD technique that uses a fitted detector efficiency curve and relates Pu concentration to the magnitude of the discontinuity at the K-edge, is also being investigated.

INTERNAL SOURCE DENSITOMETRY

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Alpha spectrometry

DESCRIPTION

Alpha spectrometry is a technique for measurement of Pu isotopic ratios through the measurement of the alpha particle energies emitted from a carefully prepared sample. A thin sample is prepared by electrodeposition or solution evaporation and placed in an evacuated chamber where it is viewed by a special alpha detector capable of recording energy. Since the alpha energies emitted in the decay of the various Pu isotopes are well known, isotopic ratios can be computed from the resultant spectrum. However, the limited resolution of available detectors limits the amount of information that can be obtained. For example, $^{238}\text{Pu}/^{240}\text{Pu}$ ratios cannot be directly determined.

BACKGROUND

A standard laboratory technique for decades.

STATUS

Widely used.

AVAILABILITY

Commercially available.

COMMENTS

The information content of the spectra are strongly dependent on the sample preparation. Alpha spectrometry is often coupled with gross alpha counting for total concentration measurements.

ALPHA SPECTROMETRY

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused. Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at fuel reprocessing facilities, either operating or shut down under mutually negotiated production limitations.

TECHNOLOGY

On-line alpha monitor

DESCRIPTION

On-line alpha monitors may be used to monitor liquid process streams in reprocessing plants for plutonium content. On-line alpha monitors are rugged specialized detectors, usually either solid state or glass scintillator detectors, for installation directly into a pipe so that the contained liquid flows over the detector face. Most plutonium isotopes decay by alpha particle emission so such a monitor can detect Pu in liquid streams. These devices could be used in a "yes/no" mode to indicate the presence of significant Pu concentrations resulting from the prohibited operation of a shutdown facility; or, they could monitor the concentration of Pu in a process stream to guard against clandestine diversion or production increases.

BACKGROUND

Glass alpha detectors have been used to monitor waste streams in a Purex-type fuel reprocessing plant.

STATUS

On-line alpha monitors are commercially available; however, they are not tamper-proofed as required for an unattended application.

AVAILABILITY

Presently available.

COMMENTS

ON-LINE ALPHA MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Laboratory analysis of samples obtained from spent fuel reprocessing or MOX fuel fabrication facilities by on-site inspectors or through cooperative sample exchanges.

TECHNOLOGY

Advanced automated controlled-potential-coulometric analyzer (AACPC)

DESCRIPTION

Controlled-potential coulometry is a laboratory electrochemical technique that is widely used for Pu assay throughout the nuclear industry. These analyses typically require considerable time from a skilled analyst. The AACPC is an automated, computer-controlled device for the controlled-potential coulometric analysis of Pu. A sample changer with a 16 sample capacity sequentially loads samples under the analysis head that hold the required electrodes, stirrer, and reagent delivery tubes. Analysis operations are automatic. A bar code reader system automatically inputs sample identification information to the controller. The automated instrument reduces the required analyst time while retaining the high precision of the method.

BACKGROUND

The AACPC has been developed and evaluated at LANL.

STATUS

Development continues. No commercial or prototype units have been fielded.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

AACPC SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Laboratory analysis of Pu product samples obtained by on-site inspectors or through other cooperative sample exchanges.

TECHNOLOGY

Advanced automated Pu titration system (AAPTTS)

DESCRIPTION

Electrochemical titration, in which the concentration of Pu in a solution is determined by the amount of a reacting reagent that must be added to a prepared Pu solution in order to exactly complete a desired reaction, is a common laboratory technique for the precise determination of Pu concentrations. The reaction endpoint is commonly sensed by a potential change at an electrode. The AAPTTS is a computer-controlled device for reagent dispensing and endpoint sensing. While it does not replace a laboratory analyst, it is expected to improve the precision of the method by eliminating operator bias in the endpoint detection.

BACKGROUND

Electrochemical titrations relying on oxidation-reduction reactions in Pu are the most common method of precision Pu analysis in the DOE complex.

STATUS

The AAPTTS is under active development at LANL.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

Computer-controlled reagent
dispensing and end-point sensing

AUTOMATED PU TITRATION SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection, installed monitor, and/or laboratory analysis of samples from reprocessing plant Pu product streams.

TECHNOLOGY

Automated high precision spectrophotometric Pu assay

DESCRIPTION

Spectrophotometric assay techniques, in which the concentration of a given element in solution is determined by the degree of light absorption by one of its specific compounds at a specific light wavelength, are particularly suited to automation because they are relatively fast and require few operations. The automated high precision spectrophotometric assay system is a computer-controlled device operating in a "flow through" manner that has been demonstrated to provide highly precise analyses of Pu content in solution. Since the unit incorporates a flow through cell, it could be developed as an installed monitoring system.

BACKGROUND

A number of spectrophotometric techniques are available for Pu determinations. This device, presently under development at LANL, uses the absorption band of PuCl_3 .

STATUS

This technology is under active development at LANL. Laboratory demonstration of the reagent addition and precision of the measurement have been completed. A laboratory prototype incorporating the computer interfacing and software is being assembled and tested.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

FLOW-THROUGH SPECTROPHOTOMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Bulk Plutonium Assay Calorimeter (BPAC)

DESCRIPTION

A calorimeter precisely measures the heat associated with the decay of radioactive materials and from this heat measurement determines the quantity of the radioactive material. Both U and Pu generate heat when they decay, but only Pu emits sufficient heat to allow accurate assay. The BPCA series of calorimeters incorporate preheaters and prediction programs to speed accurate measurements. Samples may contain a variety of matrix materials and still be properly analyzed.

BACKGROUND

Calorimetry has been used in chemical analysis for several decades. In past systems, thermal equilibrium times were long necessitating measurement times of 4 to 8 hours per sample. The BPCA series can assay sample Pu contents to better than ~1% precision in ~20 minutes.

STATUS

The BPACs were developed at Argonne National Laboratory and tested at Rocky Flats.

AVAILABILITY

Presently available.

COMMENTS

Quantity of heat indicates
amount of Pu

CALORIMETRY

2.3 TECHNOLOGIES PRIMARILY APPLICABLE TO URANIUM MEASUREMENT (INCLUDING U ENRICHMENT)

Uranium enrichment assets must be safeguarded to preclude the clandestine production of highly enriched uranium (HEU) in a facility declared to be producing low enriched uranium (LEU) for a reactor power program. This is a particular threat in gas centrifuge facilities. Unlike gaseous diffusion plants, gas centrifuge enrichment facilities can be reconfigured fairly rapidly to move from the production of low enriched uranium (LEU) to weapons-attractive highly enriched uranium (HEU). Additionally, the production and consumption of LEU must be monitored to preclude diversion to clandestine production facilities and to quantify the input to the national nuclear program.

When combined with the base measurement technologies of Section 2.1, the techniques and devices cataloged in this section comprise the primary technologies for measuring total U content in solids and solutions, verifying the ^{235}U content of fresh power reactor fuel rods, and determining U enrichment. Table 2.3 catalogs and cross references the technologies presented.

TABLE 2.3 Technologies primarily applicable to Uranium measurement

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Gravimetric analysis			*	*	*			*			M
Uranium neutron coincidence collar (UNCL)	*				*		*				M
Nuclear solution assay system			*				*	*			M
U enrichment by gamma-ray spectrometry				*	*		*	*			M
Transportable quadrupole mass spectrometer				*			*				M
In-line gas-phase enrichment monitor				*					*		M
Stationary area neutron monitoring system				*					*		M
UF ₆ flow meters				*					*		M
Transportable load-cell-based system (LCBS)				*			*				M

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Gravimetric analysis

DESCRIPTION

Gravimetric analyses are a class of laboratory analysis techniques used for the precision analysis of uranium and, less frequently, Pu. A carefully prepared solution sample is treated with a combination of chemicals that cause an insoluble compound of the U to form and precipitate. The precipitate is collected by filtering and is accurately weighed. Since the formula of the compound is known, the concentration of the U in the sample solution can be determined from the compound weight.

BACKGROUND

Gravimetric analysis may be the oldest method of chemical analysis.

STATUS

Standard developed techniques

AVAILABILITY

Commonly available

COMMENTS

GRAVIMETRIC ANALYSIS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at power reactors to confirm fresh fuel input.

TECHNOLOGY

Uranium neutron coincidence collar (UNCL)

DESCRIPTION

These devices are a special type of random driver. An interrogating neutron source and a set of neutron detectors are designed to fit as a collar on either PWR or BWR reactor fuel assemblies. The interrogating neutrons enter the fuel rods and cause the ^{235}U to fission emitting multiple neutrons. The neutron detectors detect these multiple neutron emissions, providing a signal proportional to the amount of ^{235}U in the fuel rod assembly. These units can also be tailored to measure plutonium content in large samples. The UNCL is compact and transportable.

BACKGROUND

These devices were originally developed at LANL.

STATUS

The collars are transportable and are used in the field by IAEA safeguards inspectors.

AVAILABILITY

Commercially available.

COMMENTS

A similar device (the FBR assembly counter) for analysis of fresh fast breeder reactor assemblies that contain both uranium and plutonium does not incorporate a source but rather reflects the neutrons generated by Pu decay back into the assembly as interrogating neutrons.

URANIUM NEUTRON COINCIDENCE COLLAR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at reprocessing facilities

TECHNOLOGY

Nuclear solution assay system

DESCRIPTION

This device provides highly accurate analyses of the ^{235}U content of solutions by measuring the 186 keV gamma-ray line of ^{235}U . A plastic vial containing a small sample of the solution is either placed or automatically transferred to the measurement chamber of this at-line device that incorporates two Ge gamma-ray detectors, a source for transmission correction of the gamma-ray results, a source for detector gain stabilization, a multichannel analyzer, and an associated computer and control software. System control and data analysis are automatic.

BACKGROUND

The Nuclear solution assay system was developed by LANL. A predecessor unit, the Uranium Solution Assay System (USAS) was in routine use at the Los Alamos uranium recovery facility for nearly ten years prior to development of this device.

STATUS

Mature, fielded technology.

AVAILABILITY

Presently available

COMMENTS

The Nuclear solution assay system won a 1988 "R&D 100" award. These awards, sponsored by Research and Development magazine are given annually to the 100 most significant technical developments of the previous year.

Dual gamma-ray detectors
measure transmission-corrected
uranium gamma-rays

NUCLEAR SOLUTION ASSAY SYSTEM

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

On-site inspection at uranium enrichment facilities

TECHNOLOGY

U enrichment by gamma-ray spectrometry

DESCRIPTION

The ^{235}U enrichment of input and product materials at uranium enrichment facilities can be determined using gamma-ray spectrometers operating on the "enrichment meter" principle. When homogenous gamma-ray emitting materials are sufficiently thick that the material itself presents several mean free paths of attenuating material, then the rate of characteristic gamma-rays emitted is directly proportional to the relative amount of emitter present. For the characteristic 186 keV gamma-ray of ^{235}U , a sufficiently thick sample is a few centimeters of UF_6 or UO_2 . This allows accurate determination of the U enrichment of UF_6 contained in cylinders by measurement of the 186 keV gamma-ray of ^{235}U from the outside of the cylinder. Early systems used rugged NaI gamma-ray detectors and simple dual channel electronics. Better accuracy is now obtained with modern units incorporating Ge detectors and portable multichannel analyzers (PMCA's). PMCA's can be equipped with user software to guide the enrichment measurements and calculate the result. Ultrasonic thickness gauges measure the cylinder wall thickness to correct for its effect.

BACKGROUND

The enrichment meter principle has been exploited for these measurements for decades. The PMCA-based units were developed and fielded by LANL.

STATUS

Widely used.

AVAILABILITY

Presently available

COMMENTS

U ENRICHMENT BY GAMMA-RAY SPECTROSCOPY

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

Determination of UF₆ enrichment

TECHNOLOGY

Transportable quadrupole mass spectrometer

DESCRIPTION

Mass spectrometry is a technique used for isotopic analysis of samples. Very small sample sizes are required. The sample is introduced into the mass spectrometer and electromagnetically separated into its mass components; thus, these instruments can determine the percentage enrichment of ²³⁵U in samples of UF₆ enrichment plant product and tails with excellent accuracy. The quadrupole mass spectrometer has the advantage over other mass spectrometers of being more rugged as well as being transportable. This device can be used for analysis of liquids and gases. Standards are required to be measured frequently. The individual analyses take only a short time.

BACKGROUND

This device was developed by Euratom for isotopic analysis of UF₆ samples taken from cylinders and process streams for material balance and enrichment verification. Three years of field use gave excellent results. These devices are used by IAEA safeguards inspectors.

STATUS

Development is ongoing to improve transportability and widen the instrument applications.

AVAILABILITY

Commercially available.

COMMENTS

Unit is transported by truck and can be installed in a plant and ready to use in two days. Could be engineered/tailored for tritium measurements.

TRANSPORTABLE QUADRUPOLE MASS SPECTROMETER

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

Installed monitors at uranium enrichment plants.

TECHNOLOGY

In-line gas-phase enrichment monitor

DESCRIPTION

This device provides continuous measurement of the ^{235}U enrichment of gas-phase UF_6 by combining measurement of a characteristic ^{235}U gamma-ray with a total uranium concentration. The total U concentration is determined by measuring the density of the gaseous UF_6 from the transmission of 60 keV gamma-rays through the gas-carrying piping. The unit is meant for installation on enrichment plant piping to ensure detection of unauthorized production of highly enriched uranium. The device is capable of excellent accuracy; however, deposition of material on the pipe walls is a problem.

BACKGROUND

This enrichment monitor was designed by LANL based on experience with an in-plant monitor prototype and a device of similar principle that measures UF_6 expanded into a measurement chamber from a UF_6 cylinder.

STATUS

Some techniques to compensate for deposition of material on the pipe walls have been developed. Adaptation to specific plant designs may be required.

AVAILABILITY

Presently available.

COMMENTS

IN-LINE GAS-PHASE ENRICHMENT MONITOR

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

Installed, unattended monitors at declared U enrichment plants

TECHNOLOGY

Stationary area neutron monitoring system

DESCRIPTION

Gas centrifuge low enriched uranium enrichment facilities can be reconfigured to produce highly enriched uranium. This technology consists of an array of neutron detectors installed within the cascade halls of a gas centrifuge U enrichment facility. Detector signals are received by a centralized data collection and processing system. Signal transmissions are authenticated, and units are tamper resistant/indicating. The enrichment of ^{235}U also causes enrichment of naturally-occurring ^{234}U in a predictable manner. The ^{234}U is the dominant alpha (α) particle emitter, and an increase in the enrichment increases the cascade area neutron count rate due to an increase in neutrons from the $^{19}\text{F}(\alpha, n)^{22}\text{Na}$ reaction. An increase in the ^{235}U enrichment from 3% to 90% will increase the neutron counting rate by a factor of about 50.

BACKGROUND

A prototype system has been fielded by LANL.

STATUS

Technology is well understood, and field tests have been conducted.

AVAILABILITY

Presently available

COMMENTS

Could provide assurance that the high enrichment cascades of gaseous diffusion plants remained unused. The presence of large, unshielded UF_6 cylinders in the cascade hall increases the neutron background and decreases sensitivity to over-enrichment.

AREA NEUTRON MONITORS

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

Monitors installed into the cascade system piping of a gas centrifuge enrichment facility.

TECHNOLOGY

UF₆ flow meters

DESCRIPTION

Several types of gas and mass flow meters are under investigation for use as installed monitors to verify the feed and withdrawal flow rates of UF₆ in a gas centrifuge facility. Such monitors would provide valuable information on the cascade mass balance and the feed to product and tails ratios. Some commercially available flow meters have been identified that may perform adequately. A significant disadvantage of these flowmeters is that they would require modification of the facility piping in order to accommodate installation.

BACKGROUND

The application of flow meters to IAEA safeguarding of gas centrifuge plants was suggested in safeguards training course conducted for the IAEA by Martin Marietta Energy Systems, Oak Ridge, in 1987.

STATUS

Under study.

AVAILABILITY

Mid term (2 to 5 years)

COMMENTS

UF₆ GAS FLOWMETER

VERIFICATION REQUIREMENT

Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

On-site inspection at U enrichment facilities.

TECHNOLOGY

Transportable load-cell-based system (LCBS)

DESCRIPTION

Uranium hexafluoride (UF_6) feed and product are shipped to and from U enrichment facilities in large cylinders weighing up to 14 tons (12 metric tonnes). Verification of the plant throughput requires that inspectors verify the full and tare weight of these cylinders. The LCBS is a semiportable system consisting of two load cells, a lifting fixture, and readout electronics. The device can weigh large cylinders to within a few kilograms, and avoids inspector reliance on the plant operator scales. More portable smaller units are available for weighing smaller 5-inch, 8-inch and 12-inch diameter cylinders.

BACKGROUND

The LCBS was developed at BNL.

STATUS

Mature, developed technology.

AVAILABILITY

Presently available

COMMENTS

Periodic calibrations are required.

**SMALL LOAD CELL SCALE
WITH CYLINDERS**

2.4 TECHNOLOGIES PRIMARILY APPLICABLE TO TRITIUM MEASUREMENT

Tritium emits no penetrating radiation during its decay; consequently the tritium content of containers cannot be verified by radiological counting without sampling. Calorimetry can determine the tritium content of containers by quantifying the heat generated during decay.

Technologies appropriate for verification of tritium production are few. Since tritium is not subject to international safeguards, few technologies have been developed that are appropriate for use by an on-site inspector.

Table 2.4 lists and cross-references the applicable technologies.

TABLE 2.4 Technologies primarily applicable to tritium measurement

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Non-destructive lithium screening	*					*	*				C
Liquid scintillation counting						*		*			M
Internal ionization chambers						*		*			M
Mass spectrometry						*		*			M
Calorimetry						*	*	*			M
Liquid tritium monitor						*			*		D

VERIFICATION REQUIREMENT

Verify that prohibited tritium production does not occur in civilian power reactors.

VERIFICATION REGIME

On-site inspection of power reactor control rod assemblies for undeclared feed material.

TECHNOLOGY

Nondestructive lithium screening

DESCRIPTION

To avoid the clandestine production of tritium by irradiation of undeclared target material, on-site inspectors would need to determine that control rods to be loaded into a reactor did not contain lithium (Li) for tritium production. Several technologies are under investigation for rapidly screening control rod assemblies -- normally fabricated from Ag-In-Cd alloys, or boron-containing compounds such as B_4C -- for 6Li incorporation. These techniques include photon irradiation to generate a specific neutron response; neutron interrogation coupled with gamma-ray spectrometry of the capture gamma-rays from the $^6Li(n,\gamma)^7Li$ reaction; resonance scattering of neutrons passing through the suspect assembly; and spectroscopy of neutrons backscattered from the suspect assembly during irradiation with monoenergetic neutrons.

BACKGROUND

The candidate techniques have been successfully applied to other measurement problems.

STATUS

Testing and development is underway at the INEL.

AVAILABILITY

Long term (>5 years).

COMMENTS

NEUTRON CAPTURE MONITOR FOR LITHIUM

VERIFICATION REQUIREMENT

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Central laboratory analysis of tritium recovery facility output samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Liquid scintillation counting

DESCRIPTION

Tritium is difficult to measure by most techniques since it emits only a low energy beta particle in its decay. Liquid scintillation counting is a laboratory technique developed primarily to quantify low energy beta emitters. In this technique, a carefully prepared solution sample is mixed with a special solution containing chemicals that emit light (scintillate) when they absorb a beta particle. Since the detecting chemical is intimately mixed with the sample, the limited range of the low energy beta particles is not a detriment. A vial containing the scintillation "cocktail" is then placed between two photomultiplier tubes in a light-tight box so that each light flash can be recorded. The scintillation rate can be correlated to the tritium concentration in the original sample.

BACKGROUND

A standard technique for decades. Can be used to measure Pu through alpha counting.

STATUS

Widely used.

AVAILABILITY

Commercially available.

COMMENTS

The presence of contaminating radioactive isotopes can complicate this measurement.

LIQUID SCINTILLATION COUNTING

VERIFICATION REQUIREMENT

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Central laboratory analysis of tritium recovery facility output samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Internal ionization chambers

DESCRIPTION

Ionization chambers are a standard radiation measurement device. They record each event that causes ionization of a filler gas within the sensitive portion of the chamber. They can be configured to count alpha, beta, and/or gamma radiation. For the detection of tritium, the gaseous tritium is mixed with the counting gas and the chamber records the beta decay of the tritium. Since the radioactive source is internal to the chamber the limited range of the low energy beta from tritium is not a detriment.

BACKGROUND

Well developed technology

STATUS

Widely used.

AVAILABILITY

Commercially available.

COMMENTS

INTERNAL IONIZATION COUNTER

VERIFICATION REQUIREMENT

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Mass spectrometry

DESCRIPTION

Mass spectrometry is a laboratory measurement in which a carefully prepared sample is ionized and subjected to an electromagnetic field such that ions are separated by their charge-to-mass ratio and measured. Mass spectrometry is widely used to establish the isotopic ratios of Pu, to determine uranium enrichment, and to determine tritium. It is a highly precise and accurate technique and is the yardstick against which all other isotopic ratio measurements are compared. By the addition of certain standards, a technique known as isotopic dilution mass spectrometry can yield very precise results on total concentration.

BACKGROUND

A standard laboratory technique for decades.

STATUS

Well developed.

AVAILABILITY

Commercially available.

COMMENTS

MASS SPECTROMETRY

VERIFICATION REQUIREMENT

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Central laboratory analysis of samples obtained by on-site inspectors or through sample exchanges.

TECHNOLOGY

Calorimetry

DESCRIPTION

Calorimeters precisely measure the heat generated by the radioactive decay of tritium. The heat production can be directly related to the total quantity of a pure radioactive isotope in a closed container.

BACKGROUND

Calorimetry has been used for chemical analyses for decades. Its application to radioactive materials is more recent, but the principles are the same and the use of calorimeters is well understood and documented.

STATUS

Well developed.

AVAILABILITY

While calorimeters are widely available, ones designed for use with radioactive materials are currently produced by certain DOE laboratories, such as ANL and Mound.

COMMENTS

Quantity of heat indicates
amount of tritium

CALORIMETRY

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Cooperative on-site installation of liquid effluent monitors on the site of shutdown tritium recovery facilities.

TECHNOLOGY

Liquid tritium monitor

DESCRIPTION

A liquid stream (effluent from a tritium recovery facility) is drawn through a Nafion membrane tube bundle that separates the tritiated water from radioactive interferences. This purified tritium stream is then measured on line by counting radioactive decays in a flow-through 20-l internal ionization chamber.

BACKGROUND

This instrument has been in operation since 1987 at the ICPP Trickle Bed Recombiner.

STATUS

Fielded process monitoring technology, not hardened or tamper proofed for a verification environment.

AVAILABILITY

Presently available.

COMMENTS

LIQUID TRITIUM MONITOR

2.5 TECHNOLOGIES FOR THE MEASUREMENT OF OTHER IMPORTANT ATTRIBUTES

An adequate nuclear material control system requires measurements beyond those specifically oriented to measurements of the species of interest. Some example technologies are those applicable to the verification of compliance with a facility shutdown, determination of the operating history of a nuclear reactor, and devices to monitor the operation of a nuclear fuel reprocessing facility (volumes, densities, transfers, etc.). Technologies of this type are cataloged in this section (see Table 2.5).

The adequate detection of clandestine facilities, particularly clandestine uranium enrichment or isotope separation facilities, is a potential verification problem. Laser isotope separation (LIS) facilities, and gas centrifuge enrichment plants can be low signature facilities.

TABLE 2.5 Technologies for the measurement of other important attributes

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Cerenkov glow viewing devices	*	*	*				*				M
Fork detector	*	*	*				*				
Python device	*	*	*						*		M
Cf-252 source-driven noise analysis system	*	*	*				*		*		D
Isotope correlation technique	*	*	*				*	*			M
Track etch power monitor	*					*			*		M
He-3 reactor power monitor	*					*			*		M
Reactor power monitoring by neutrino detection	*					*			*		C
Unattended gamma-ray spectrometers	*	*	*	*	*	*			*		M
Dynamic materials and control systems (DYMAG)	*	*	*	*	*	*			*		M
Load cell monitors			*						*		M
Electromanometer			*						*		M
Process monitoring systems			*	*	*	*			*		M
Mobile measurement systems	*	*	*	*	*	*	*				M
Retrospective confirmation of environmental trends (RECET)	*	*	*	*	*	*				*	D
Passive cryogenic sampler			*			*				*	M

TABLE 2.5 (Continued)

Technology	Primary facilities						Useful for				Maturity
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	On-site inspection	Lab confirmation	Installed monitor	Environmental mon	
Particle inlet mass spectrometry			*	*	*					*	M
Remote ambient sulfur detector				a						*	M
Aerial radiation measurement systems	*	*	*	*	*	*				*	M
Airborne thermal imaging	*					*				*	M
NASA/NOAA Landsat thematic mapper	*					*				*	M
a Heavy water enrichment plant											

THIS PAGE INTENTIONALLY LEFT BLANK

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Confirmation of irradiation of fuel assemblies in reactor spent fuel storage ponds and reprocessing facilities.

TECHNOLOGY

Cerenkov glow viewing devices

DESCRIPTION

Cerenkov glow is the blue glow that surrounds highly radioactive material when immersed in water. Since fresh, unirradiated fuel rods do not exhibit this glow and highly radioactive "spent" fuel rods do, the Cerenkov glow viewing technique is a simple, nonintrusive method of spent fuel verification. The Cerenkov glow from spent fuel stored under water can be viewed by standard night vision devices or by devices specifically designed for this purpose. This is a semi-qualitative method. It confirms that the submerged fuel has been irradiated, and the intensity of the glow can be roughly correlated to fuel burn up and cooling period.

BACKGROUND

The IAEA started using commercially available night vision devices about 10 years ago for observing Cerenkov glow.

STATUS

Development work is continuing under IAEA contracts. The technique is known to have some drawbacks which are now under intensive study. Among these are interferences from ambient fuel pool lighting. However, this method is regarded as a convenient one for use by IAEA inspectors.

AVAILABILITY

Some devices are commercially available.

COMMENTS

CERENKOV GLOW VIEWING DEVICE

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at nuclear reactors.

TECHNOLOGY

Fork detector

DESCRIPTION

The fork detector is a transportable device to aid inspectors in verifying that irradiated power reactor fuel assemblies are legitimate and have not been modified. The detector head, called the fork, is a U-shaped piece of polyethylene sized to fit around a standard fuel assembly. The fork is supported by a long watertight pipe that allows the inspector to maneuver the fork into a measurement position around a spent assembly in a spent fuel pool. In use, the fork handle is mounted to the pond bridge. The arms of the fork contain neutron and gamma-ray detectors. Wires traveling through the pipe connect the fork to counting electronics (the GRAND-1 system) at the inspector location. Neutron and gamma-ray measurements are made on partially withdrawn fuel assemblies. Correlation of the neutron and gamma-ray measurements can detect fuel assembly anomalies such as missing fuel pins or exposure differences. PWR assemblies are usually measured at one point on their axis, and if the result is anomalous further measurements are taken along the assembly length. The electronics can be computer supported.

BACKGROUND

The fork detector and electronics were developed by LANL in 1982 and underwent modifications in subsequent years. The fork detector is a routine IAEA inspection instrument.

STATUS

Well-developed, mature technology

AVAILABILITY

One version of the fork detector is commercially available.

COMMENTS

While comparisons of fuel assemblies at the same reactor are simple and accurate, intercomparisons between facilities are complicated by differences in boron content of the spent fuel pool water.

FORK DETECTOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at nuclear reactors.

TECHNOLOGY

Python device

DESCRIPTION

The Python device aids inspectors in verifying that irradiated power reactor fuel assemblies are legitimate and have not been modified. It is in some respects similar to the Fork detector; however, the Python is permanently installed in a spent fuel canal, and fuel assemblies to be measured are brought to the detector unit. Two detection heads containing collimated gamma-ray and neutron detectors lie on either side of the fuel assembly during measurement. Radiation is measured along the entire length of the assembly as the assembly is slowly withdrawn. Unlike the Fork detector, the Python device can use a pneumatically-shuttled ^{252}Cf neutron source for active interrogation of the assembly's fissile content.

BACKGROUND

The Python device was developed at CEA/CEN Cadarache in France to address criticality safety concerns during spent fuel transport.

STATUS

Well-developed, mature technology

AVAILABILITY

Presently available

COMMENTS

PYTHON DEVICE

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitoring system at power reactors to confirm fresh fuel input and spent fuel output.

TECHNOLOGY

Cf-252 source-driven noise analysis system

DESCRIPTION

A ^{252}Cf neutron source and two detector systems would be located adjacent to a fuel element (fresh or spent) to verify by noise analysis signatures that the fuel element is as permitted. Scintillation detectors can be used for fresh fuel and fission chambers for spent fuel. This system would compare the signature of each tested fuel element with that of permitted fuel elements. This device could be used in both a "yes/no" mode to indicate deviations or to quantify the deviation and locate in what portion of the fuel bundle the deviation occurred.

BACKGROUND

This technology is under development at ORNL. Measurements have been performed with mockups of naval fuel assemblies showing that even minor modifications of the fuel elements can be detected.

STATUS

Under development.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

CF-252 SOURCE-DRIVEN NOISE ANALYSIS SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspections at the dissolver tank of spent fuel reprocessing facilities.

TECHNOLOGY

Isotope correlation technique (ICT)

DESCRIPTION

An isotope correlation is a relation, expressed either algebraically or graphically, between the amounts of certain fission products or heavy metal isotopes present in irradiated fuel and some other quantity of interest, such as Pu content, U/Pu ratio, etc.. ICT provides an independent verification of nuclear material production to detect off-normal power reactor and/or reprocessing plant operations. The production of undisclosed weapons-grade SNM in production facilities, the overloading of reactor assemblies with fertile material to increase SNM production, and removal and reprocessing of low-burn up assemblies to recover weapons-grade Pu are some of the diversions that can be detected by ICT.

BACKGROUND

The ICT was evaluated under the IAEA's TASTEX program to improve reprocessing plant safeguards. The ICT program has been applied by ANL to domestic and international fuel cycle operations involving many classes of reactor systems operating in a variety of modes.

STATUS

Techniques are well-developed. The application of ICT to non-U. S. power/production reactor fuel cycles will require modeling several reactor systems capable of weapons-grade Pu production.

AVAILABILITY

COMMENTS

Effect of Partial U overloading
on Correlation #2

ISOTOPE CORRELATION

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Installed monitors at power and production reactors.

TECHNOLOGY

Track etch power monitor

DESCRIPTION

The track etch power monitor (TEPM) is a device designed to be emplaced inside a reactor vessel and to record the reactor power level for periods of up to one year. The TEPM incorporates a 35 mm wide plastic film that is drawn by a fixed rate motor over a set of foils containing fissionable nuclides. As neutrons from the reactor operation bombard the fissionable foils the nuclides fission and some of the fission fragments pass through the plastic leaving holes that can be etched and counted after retrieval of the device. The density of these fission "tracks" is proportional to the reactor neutron flux and thus to the reactor power. The unit incorporates a selection of fissionable nuclides having different fission thresholds thus allowing rough determination of the reactor neutron spectrum.

BACKGROUND

The TEPM was designed by GE Vallecitos Nuclear Center and evaluated by the US National Institute of Standards and Technology (NIST) as a US task in support of the IAEA.

STATUS

The unit has been field tested and in 1983 the IAEA had one unit available for field use.

AVAILABILITY

Presently available.

COMMENTS

The field units require external AC power. This limits their applicability and compromises their tamper resistance.

TRACK ETCH REACTOR POWER MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Installed monitors at nuclear power and production reactors.

TECHNOLOGY

He-3 reactor power monitor

DESCRIPTION

The He-3 reactor power monitor is in limited use by the IAEA to record the actual power history of nuclear reactors. The unit employs a He-3 neutron detector to monitor the neutrons leaking from the core of a reactor during operation. The neutron detection rate is directly related to the reactor power. The IAEA unit is microprocessor controlled and incorporates tamper-resistant and tamper-indicating features.

BACKGROUND

The IAEA had one field unit available for use in 1983.

STATUS

Developed and field tested.

AVAILABILITY

Presently available.

COMMENTS

HE-3 REACTOR POWER MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

Verify the tritium production of declared facilities to confirm compliance with the negotiated tritium production limitation.

VERIFICATION REGIME

Cooperatively-placed monitors at nuclear power or production reactors.

TECHNOLOGY

Reactor power monitoring by antineutrino spectroscopy

DESCRIPTION

Soviet researchers have exploited the highly penetrating nature of antineutrinos to determine remotely the operating status (on/off) and the power level of operating reactors by determining the energy spectra of the antineutrinos associated with the core radioactivity. Antineutrinos are generated during the decay of core fission products. Antineutrinos penetrate matter (concrete, steel, earth) very efficiently. Researchers used a specialized detector to measure these antineutrinos from a distance of about 18 meters and successfully recorded the operating status of the reactor. Other researchers, studying neutrino behavior, have measured the antineutrino spectra from an operating PWR from distances up to 65 meters. INEL researchers, using a moments analysis applied to these published spectra, have successfully determined the percentage of core fissions occurring in ^{239}Pu and the percentage in ^{235}U . This might allow direct tracking of reactor ^{239}Pu production.

BACKGROUND

Soviet research was conducted at the Roven nuclear power plant, a VVER-440 reactor, by researchers from the Kurchatov Nuclear Power Institute. Other measurements have been conducted at SRS, Gösigen (Switzerland), and Bugey and Grenoble (France).

STATUS

To date, antineutrino spectroscopy systems have been highly specialized physics research instruments. However, the Soviets offered to develop an antineutrino-based reactor power monitor for the IAEA.

AVAILABILITY

Mid-term. Three to five years would be required to field a prototype.

COMMENTS

At present, the ^{239}Pu content of an operating reactor core, and generally of its spent fuel, are determined indirectly by calculations based on the reactor power history. Antineutrino spectroscopy might provide this content directly.

NEUTRINO-BASED REACTOR POWER MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Continuous, on-line monitoring of radioactive materials.

TECHNOLOGY

Unattended gamma-ray spectrometers

DESCRIPTION

Gamma-ray spectrometers are routinely used to determine the content of radioactive materials in a variety of samples. While they are usually operated "hands on" by knowledgeable scientists, units have been developed that operate accurately while unattended. These unattended spectrometers are computer controlled and some use the technique of pulse injection with subsequent removal to provide self calibration and system performance monitoring. Hardened tamper-proofed units of this type could be installed near power reactors to confirm their operating status or could monitor critical streams in reprocessing plants to determine throughput.

BACKGROUND

Unattended gamma-ray spectrometers have been used for more than a decade at the INEL to monitor reactor effluent activity.

STATUS

While the measurement technology is developed, none of the field units are hardened or tamper-proofed.

AVAILABILITY

Presently available

COMMENTS

Process piping

Pulser-equipped
Ge detector

Computer and
electronics

UNATTENDED GAMMA-RAY SPECTROMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at SNM bulk handling facilities.

TECHNOLOGY

Near real-time accountancy (NRTA) or Dynamic materials and control (DYMAC) systems

DESCRIPTION

As originally envisioned, DYMAC and NRTA systems were integrated SNM safeguards systems that incorporated on-line sensors, capable of measuring SNM concentrations, solution volumes and flow rates, with computer-based accountancy systems in order to provide frequent accounting of all of the SNM in a bulk handling plant such as a spent fuel reprocessing facility. A variety of sensors and computer systems have been developed. Many NRTA systems incorporate few or no on-line sensors but accept operator-supplied accountancy data and perform material balances at approximately 10 day intervals.

BACKGROUND

NRTA concepts were investigated at several US laboratories, and were a development task under the IAEA TASTEX project for development of procedures for reprocessing plant safeguards.

STATUS

DYMAC systems, as originally conceived, suffer from a limited number of on-line sensors. Operator-supplied NRTA systems may lack the authentication required for safeguards verification. The special recovery project at SRS incorporates safeguards and process control devices to provide both process control and NRTA data. The new MOX fuel fabrication facility at Tokai, Japan operates unattended and safeguards is provided via a DYMAC concept.

AVAILABILITY

All NRTA and DYMAC systems are custom designed and plant specific.

COMMENTS

Systems of this type are expected to decrease the required IAEA inspector commitment at large SNM bulk handling facilities.

DYMAC SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Installed monitors at fuel reprocessing facilities to record accountability tank content and solution transfers.

TECHNOLOGY

Load cell monitors

DESCRIPTION

Strain gauge load cells can be installed to measure and record the weight of critical process tanks in fuel reprocessing facilities. Tanks of choice would probably be the input accountability tank and the output Pu product storage or transfer tank(s). The total tank weight, corrected for tare, is indicative of plant throughput, and weight changes can be monitored to record the number of transfer operations. Load cells are rugged and reliable and are available in a wide variety of weight ranges.

BACKGROUND

These devices were evaluated for accountability measurements as part of the IAEA TASTEX project to improve reprocessing plant safeguards.

STATUS

Work at Dounreay (UK) has shown that, with proper attention to tank isolation, load cells can provide rapid accurate measurements of liquid contents. This type of system is being installed on the input and product accountability tanks at the UK's new THORP reprocessing plant.

AVAILABILITY

Presently available.

COMMENTS

As the total load cell capacity increases, the sensitivity to minor changes in load generally decreases. Load cell installation would require plant modifications that might limit their application in a verification regime.

Installed load cells

LOAD CELL MONITORS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Installed monitors at spent fuel reprocessing facilities to record tank volumes.

TECHNOLOGY

Electromanometer

DESCRIPTION

The electromanometer is a computer-controlled device for continuously monitoring the level and density of liquid in a process tank. The device works by measuring the pressure differential between a tube installed near the bottom of the tank and others at higher levels. Solution temperature and total tank weight (from installed load cells) can also be monitored. Electromanometers, if installed on reprocessing plant accountability and storage tanks, can alert an inspector or monitoring agency to all material transfers to and from those tanks. Measured densities can, in some cases, be converted to Pu or U concentrations if other values (such as the acid concentration) are known.

BACKGROUND

Electromanometers were evaluated by the IAEA as a part of the TASTEX program for improvement of reprocessing plant safeguards.

STATUS

Substantial design information available.

AVAILABILITY

Presently available.

COMMENTS

Air manometers, read visually or via strip chart, are standard process control devices.

Level, density, and temp sensors

ELECTROMANOMETER

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Monitoring and recording of solution transfer operations at spent fuel reprocessing facilities.

TECHNOLOGY

Process monitoring systems

DESCRIPTION

Process monitoring systems consist of an array of sensors installed on critical valves and lines of fuel reprocessing facilities to provide status information to the plant operators. Sensors may include valve position monitors, tank volume indicators, flowmeters, transfer jet monitors, etc.. The system records the timing of valve actuation, and tracks solution movements through the facility.

BACKGROUND

A process monitoring system is installed at the ICPP at the INEL, at a processing facility at LANL, and at other DOE facilities. A dual purpose process monitoring/safeguards accountability system is installed at the special recovery project at SRS.

STATUS

Technology is available but plant retrofitting can be a problem.

AVAILABILITY

Presently available.

COMMENTS

Authentication of the monitoring system information is a problem for inspectors. Process monitoring systems capable of inspector authentication are being investigated as a part of the IAEA LASCAR program to develop methods for safeguarding large scale reprocessing facilities.

PROCESS MONITORING SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Support of on-site inspectors.

TECHNOLOGY

Mobile measurement systems

DESCRIPTION

Mobile laboratories, usually housed in a truck or trailer and containing a variety of devices for the measurement of SNM, have been fielded. MONAL, one such system designed at LANL, contained a neutron generator and several neutron detectors for "active" non-destructive determinations. The INEL Mobile Radiological Laboratory (IMRL) contains a number of gamma-ray spectrometers along with other radiation detection equipment. These units incorporate computers to assist the inspectors. All could be air transportable.

BACKGROUND

These labs have been used for a variety of inspection purposes.

STATUS

These units are generally custom designed for a measurement application.

AVAILABILITY

Mid term (2 to 3 years). While all of the components are commercially available, proper engineering and construction can require 2 to 3 years. Modification of an existing unit such as the IMRL could occur more quickly.

COMMENTS

MOBILE LABORATORY

VERIFICATION REQUIREMENT

Identify suspected SNM and/or tritium handling facilities for challenge inspections.

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Sampling and subsequent analysis of biota at a suspect site.

TECHNOLOGY

Retrospective confirmation of environmental trends (RECET)

DESCRIPTION

RECET may allow a time history of processing activities related to SNM and tritium production to be developed through the monitoring of biological accumulators. Biological monitoring is used routinely in the analysis of the uptake of a variety of chemicals by biological media. Specific bioaccumulators for a number of heavy metals have been identified. Since some bioaccumulators record an inherent time history (e.g. tree rings) the possibility of time history monitoring through bioaccumulators appears feasible.

BACKGROUND

INEL studies have identified some heavy metal bioaccumulators. Tree rings have been monitored for tritium accumulation in the US and Japan.

STATUS

Research on specific bioaccumulators required.

AVAILABILITY

Techniques for some species available.

COMMENTS

RECET METHOD

VERIFICATION REQUIREMENT

Identify suspected SNM and/or tritium handling facilities for challenge inspections.

VERIFICATION REGIME

Cooperative collection of environmental samples for subsequent laboratory analysis.

TECHNOLOGY

Passive cryogenic sampler

DESCRIPTION

This unit is a portable, passive cryogenic sampler designed for the collection of whole air samples without loss or concentration of any atmospheric constituents. Design capabilities include:

- o Sample volume capacity greater than 100 standard liters.
- o No vertical dimension greater than 50 cm or horizontal dimension greater than 15 cm.
- o Operation without electrical power.
- o Sampling lifetime greater than two hours.
- o Total gross weight less than 20 kg.
- o Tamper resistant/indicating.

BACKGROUND

This sampler was developed at the INEL.

STATUS

Development completed.

AVAILABILITY

Presently available.

COMMENTS

PASSIVE CRYOGENIC AIR SAMPLER

VERIFICATION REQUIREMENT

Identify suspected SNM and/or tritium handling facilities for challenge inspections.

VERIFICATION REGIME

Central laboratory analysis of cooperative wipe samples of suspected SNM handling facilities.

TECHNOLOGY

Particle inlet mass spectrometry (PIMS)

DESCRIPTION

PIMS is a method for the isotopic analysis of individual U- and Pu-bearing particles from collected samples without manually locating or isolating the desired particles. The technique takes a fraction of the solid sample (wipe sample) and introduces the particles into the atmospheric ionization mass spectrometer and monitors the signal for $^{235}\text{UO}^+$ and $^{238}\text{UO}^+$ ions. Isotopic ratios perturbed from natural abundances suggest recent SNM handling activities.

BACKGROUND

Particle analyses have been commonly used at SNM facilities.

STATUS

Presently under development.

AVAILABILITY

Long-Term (>5 years)

COMMENTS

PARTICLE INLET MASS SPECTROMETER

VERIFICATION REQUIREMENT

Identify suspected SNM and/or tritium handling facilities for challenge inspections.

VERIFICATION REGIME

Cooperatively-deployed ambient air monitoring equipment.

TECHNOLOGY

Remote ambient sulfur detector

DESCRIPTION

A 21-kg flame photometric detector was developed capable of detecting parts-per-billion concentrations of ambient sulfur compounds. This detection limit is sufficient to determine if a Girdler-Sulfide heavy water enrichment plant is operational at distances on the order of hundreds of kilometers.

BACKGROUND

This small, compact detector was developed in 1989.

STATUS

Development complete.

AVAILABILITY

Presently available.

COMMENTS

REMOTE AMBIENT SULFUR DETECTOR

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused. Identify suspected SNM and/or tritium handling facilities for challenge inspections.

VERIFICATION REGIME

Aerial sensing of SNM activities from low-flying aircraft.

TECHNOLOGY

Aerial radiation measurement systems

DESCRIPTION

Aerial radiation measurement systems routinely survey US DOE sites for environmental compliance. If treaty provisions permitted, aerial radiation mapping systems could be employed to detect prohibited radiation handling operations. US airborne radiation mappers in routine use consist of large arrays of NaI gamma-ray detectors (neutron monitors are available) normally mounted externally on a helicopter platform. A specially-designed data acquisition and storage system acquires and stores gamma-ray spectral data from the detector array. Equal in importance to the radiation detection system is a precision navigation system that determines the position of the helicopter (in X-Y coordinates) to within 3 meters. This navigational system may rely solely on ground-based sensors or may use a differential Global Positioning technique. The helicopter flies a raster scan pattern over the survey area. Highly detailed radiation isopleths scaled to available maps of the surveyed area can be developed. Significant changes in radiation profiles can easily be detected.

BACKGROUND

An aerial radiation measurement capability was developed in the late 1950's for uranium exploration. The US operating contractor is EG&G Energy Measurements at the DOE's Remote Sensing Laboratory (RSL).

STATUS

Aerial gamma-ray measurement systems are well-developed and supported.

AVAILABILITY

Presently available

COMMENTS

Intrusive access to the relevant airspace at overflight altitudes of 300 ft. or less would be required.

Helicopter flies a
precise grid pattern

AERIAL RADIATION MEASUREMENT SYSTEM

VERIFICATION REQUIREMENT

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Aerial real-time thermal imaging from an aircraft platform.

TECHNOLOGY

Airborne thermal imaging

DESCRIPTION

Aerial thermal imaging from an aircraft platform could be employed to ensure that certain prohibited facilities were not operating. Systems are available that employ both real-time video thermal imaging (Barr and Stroud, for example) and digital multispectral scanning. Both systems have spatial resolutions on the order of 0.6 to 0.8 m. The video imaging systems are relatively inexpensive and allow real-time review of the image; however, they provide only thermal spectral scanning. Their response is difficult to quantify. An example of a digital multispectral scanning camera, the Daedalus 1268, is a digital 11 band scanner. The available bands cover the spectrum from blue light through thermal infrared (IR). The channels include the visible and thermic channels of the Landsat satellite. Internal reference standards are provided in the digital multispectral camera systems to allow quantification of the detected radiance. These systems are expensive. Both of these systems are generally flown on fixed wing aircraft. They are sensitive to thermal differences on the order of 0.1° to 0.25°C. These sensitivities are more than sufficient to detect reactor operations.

BACKGROUND

Aerial thermic mapping is conducted routinely for the DOE by the Remote Sensing Laboratory (Las Vegas). In addition to the required sensors, the RSL operates a complex digital image processing system to review and present thermal, optical, and radiometric images.

STATUS

Well developed and supported

AVAILABILITY

Presently available

COMMENTS

Requires access to the relevant airspace at altitudes of about 10,00 feet. The transient nature of a purely thermal signal may limit the usefulness of this technique for challenge inspections that would require prior notice.

AIRBORNE THERMAL MAPPING

VERIFICATION REQUIREMENT

Identify suspected SNM and/or tritium handling facilities for challenge inspections.

Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Thermal mapping via commercial satellite

TECHNOLOGY

NASA/NOAA Landsat thermatic mapper

DESCRIPTION

The NASA/NOAA thermatic mapping satellites provide low resolution (about 100 meter) infrared surveillance worldwide. Each global position is revisited on about a 16 day schedule. The Landsat performance, while insufficient to resolve the individual thermal plumes of each reactor in a common discharge complex or to monitor the status of reactors that are cooling-tower equipped, is generally sufficient to detect the thermal plume from reactor operations that discharge to a cooling pond or to a river. For example, cooling pond discharges from the stricken Chernobyl reactor are clearly discernable as ON prior to the accident and OFF following. The Landsat series also incorporate optical scanners with about 30 meter resolution.

BACKGROUND

The first in the Landsat series was launched in 1975.

STATUS

Images are commercially marketed. Digital image processing workstations allow detailed review of individual images and overlays and are a necessity for adequate review.

AVAILABILITY

Presently available.

COMMENTS

Overlays of Landsat thermal images with higher resolution optical images from either the Landsat or the commercially available images from the French SPOT satellite (No thermal channel but optical resolution to 10 meters) can improve the correlation of thermal features to facilities.

LANDSAT THERMIC MAPPING

3.0 CONTAINMENT AND SURVEILLANCE DEVICES

Containment and surveillance (C&S) devices are important safeguards technologies. C&S devices include portal monitors, that survey personnel and vehicles for hidden SNM; cameras and surveillance devices, that record activities in critical plant areas; seals to secure and identify containers, assemblies, and facilities; and systems designed to monitor the status of C&S devices in real time, in order to provide an immediate indication of compromise or prohibited activity. An index to the cataloged technologies is provided in Table 3.0.

Personnel SNM portal monitors are generally well developed. Vehicle portal monitors, while available, are less highly developed. No devices have been cataloged that monitor either personnel or vehicles for tritium. These devices may be required depending on the treaty scenario. Tritium monitoring could be a technical challenge because of the ease of concealment and because a small quantity has strategic value.

Surveillance cameras, operating on motion-sensing, time interval, and random activation are routine instruments of both US and IAEA safeguards. They are a highly important component of reactor safeguards. Improved systems for screening films and/or tapes for suspicious activity would be beneficial.

The DOE is conducting a program to develop and evaluate sealing and tagging technologies appropriate for treaty applications. Since these systems are reviewed elsewhere, they are not repeated herein. This section summarizes sealing systems that have been applied to SNM safeguards. SNM safeguards sealing systems have been significantly improved over the last decade with the advent of field verifiable seals such as the fiber optic COBRA and the VACOSS sealing systems. However, certain seals, primarily those directed to sealing and identifying spent fuel assemblies, require reactor-specific designs. Seals for identification of fast reactor assemblies and blankets must withstand storage under liquid sodium. Safeguards at on-load-refuelable reactors, such as the Canadian CANDU machines, are highly C&S dependent.

THIS PAGE INTENTIONALLY LEFT BLANK.

TABLE 3.0 Containment and surveillance devices

Technology	Primary facilities						Type			
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	Portal monitors	Surveillance	Seals	Status monitors
Hand-held SNM monitors	*	*	*	*	*	*	*			
Gamma-ray-based SNM portal monitors	*	*	*	*	*	*	*			
Neutron-based SNM portal monitors	*	*	*	*	*	*	*			
CORONA radiation detection system	*	*	*	*	*	*	*			
Be(γ ,n) core discharge monitor	*							*		
Laser surveillance system	*	*	*					*		
Crane motion monitors	*	*	*					*		
Wireless alarm transmission of container handling (WATCH)	*		*	*	*	*		*		
Authenticated item monitoring system (AIMS)	*		*	*	*	*		*		
Tamper-indicating container and AIMS	*	*	*	*	*	*		*		
Surveillance cameras (film)	*	*	*	*	*	*		*		
Modular integrated video system (MIVS)	*	*	*	*	*	*		*		
Portable surveillance unit (PSU)	*	*	*	*	*	*		*		
Digital image processing for materials control	*	*	*	*	*	*		*		
Cobra seal system (fiber optic seal system)	*	*	*	*	*	*			*	

TABLE 3.0 (Continued)

Technology	Primary facilities						Type			
	Reactors	Spent fuel storage	Reprocessing	U Enrichment	Fabrication	Tritium Production	Portal monitors	Surveillance	Seals	Status monitors
Adhesive seals	*	*	*	*	*	*			*	
Cup-and-wire seal (E seal)	*	*	*	*	*	*			*	
Shrink-tubing seal			*	*					*	
VACOSS electronic sealing system	*	*	*	*	*	*			*	
Ultrasonic seals	*	*							*	
Remote continual verification system (RECOVER)	*	*	*	*	*	*				*

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Personnel, package, and vehicle monitoring at all SNM facilities

TECHNOLOGY

Hand-held SNM monitors

DESCRIPTION

These devices are rugged, portable, hand-held monitors that detect radiation from SNM. They use neutron and/or gamma-ray sensitive detectors, and automatically discriminate real signals from these materials from background radiation. An audible alarm sounds if SNM is detected. They run on batteries. While they are not designed for accurate measurements, some of these devices have a second mode in which more precise measurements can be performed.

BACKGROUND

Some models were designed at Los Alamos National Laboratory (LANL).

STATUS

These devices are commonly used at nuclear facilities and are commercially available. LANL has a on-going program to develop improved devices.

AVAILABILITY

Commercially available.

COMMENTS

These instruments have been successfully used to inspect facilities licensed to enrich non-SNM isotopes for evidence of prohibited SNM enrichment.

SNM SEARCH AND SURVEY MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Portal monitoring of personnel and vehicles

TECHNOLOGY

Gamma-ray-based SNM portal monitors

DESCRIPTION

SNM portal monitors are devices through which personnel and/or vehicles entering or leaving a facility must pass. Some units are "pass through" while others are of the "wait-in-monitor" type. The most common units contain gamma-ray detectors designed to detect the presence of small amounts of SNM. Supporting electronics generate an alarm if the detected radiation exceeds a preset level.

BACKGROUND

Units of this type are deployed at every US facility handling SNM.

STATUS

Well developed, mature technology.

AVAILABILITY

Presently available.

COMMENTS

Detection of SNM by these monitors can be frustrated by packaging the SNM in shielding.

PERSONNEL PORTAL MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Portal monitoring of personnel and vehicles

TECHNOLOGY

Neutron-based SNM portal monitors

DESCRIPTION

SNM portal monitors are devices through which personnel and vehicles entering or leaving a facility must pass. Some units are "pass through" while others are of the "wait-in-monitor" type. While the most common units rely on gamma-ray detection, devices have been developed and tested that use neutron detection to detect the presence of small amounts of SNM. Supporting electronics generate an alarm if the neutron emission rate exceeds a preset level. Since neutrons are less easily shielded than are gamma rays, these devices can give better protection against diversion of SNM in shielded containers and vehicles.

BACKGROUND

Neutron detection based monitors have been recently developed at LANL.

STATUS

Prototype pedestrian monitors are under testing at the Savannah River Site. A neutron-detection-based vehicle monitor is operating at Pantex.

AVAILABILITY

Technology is mature and is being commercialized.

COMMENTS

Neutron-based vehicle portal monitors

VEHICLE PORTAL MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Perimeter/portal monitoring at SNM handling and storage facilities and at operating tritium separation facilities to detect prohibited SNM.

TECHNOLOGY

CORONA radiation detection system

DESCRIPTION

The CORONA system would provide a method of monitoring portals and perimeters for SNM movement. The CORONA system is an integrated system consisting of a set of small (10cm X 8cm X 25cm) detector and electronics packages linked by twisted pair phone-type wires to a central alarm processor. Detectors are deployed at portals and/or around the perimeter of the facility to be monitored. The detectors may be gamma-ray or neutron detectors and the detector packages incorporate battery backup and data storage capability that allows each unit to function for 50 hours if the twisted pairs are removed or cut breaking the link to the central processor. The "state-of-health" of the remote detector units and of the central processor are continually monitored via handshake intercommunications. The central alarm processor displays, logs, and alarms each unusual occurrence in the fielded detector stations.

BACKGROUND

The CORONA radiation detection system is the result of integration of several mature technologies.

STATUS

CORONA systems have been operating in the field since 1988. Detectors for interior applications (in buildings, embedded in walls, etc.) are the best developed. Larger and more sensitive detectors for outdoor applications are at the prototype stage.

AVAILABILITY

Presently available, fielded system

COMMENTS

Each detector station can be used manually as a portable survey device. Count rate LEDs indicate counting rate locally, and when the disconnected unit is reconnected to the alarm processor the local memory responds with information accumulated during the disconnect.

CORONA RADIATION DETECTION SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed surveillance device at on-load refuelled power reactors.

TECHNOLOGY

Be(γ ,n) core discharge monitor

DESCRIPTION

This device, developed for use at on-load refueled CANDU reactors, registers events indicative of the discharge of spent fuel from the reactor core. Beryllium (Be), when bombarded by gamma rays over 1660 keV in energy, emits neutrons via a (γ ,n) reaction. Spent reactor fuel typically emits several gamma rays with energies above this threshold. The Be(γ ,n) core discharge monitor consists of Be monitored by a neutron-detecting fission chamber, and electronics to record the neutron count rate versus time. When this device is located near the refuelling machine of an on-load refueled reactor, it registers a sharp increase in neutron counting rate each time a fuel element is discharged. The relatively high gamma-ray energy required to induce a signal provides significant background discrimination.

BACKGROUND

Developed by LANL and field tested at a CANDU reactor.

STATUS

Developed and prototype tested.

AVAILABILITY

Presently available

COMMENTS

CORE DISCHARGE MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at reactors, away-from-reactor spent fuel storage, and spent fuel reprocessing facilities.

TECHNOLOGY

Laser surveillance system

DESCRIPTION

This device is designed for use at spent fuel storage pools. Two beams of laser light scan an underwater plane. When a fuel assembly penetrates this plane of light, the system response changes, and the computer controller calculates the position in the pool of the disturbance. The pool is scanned every 15 seconds and a map of the assemblies in the pool is updated. The control computer can be programmed to separate out anything which is relocated by procedure or agreement, and is then able to list anything moved in a prohibited manner.

BACKGROUND

This system is being developed for the IAEA possibly to supplement cameras which currently record movements in and around spent fuel pools.

STATUS

The laser surveillance system, which has given satisfactory results so far, is still being tested by the IAEA and at the Joint Research Centre at Ispra.

AVAILABILITY

Short term (1 to 2 years)

COMMENTS

LASER SURVEILLANCE SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed monitors at reactors, away-from-reactor spent fuel storage, and spent fuel reprocessing plant input storage pools.

TECHNOLOGY

Crane motion monitors

DESCRIPTION

Highly radioactive spent fuel elements are stored under water (or sodium, for FBR assemblies) and are moved remotely by cranes. Crane motion monitors record crane movements for later review by inspectors. Since the location to which the crane is moved can be correlated to fuel assembly storage locations, these recorded entries can reveal undeclared movements.

BACKGROUND

Proof-of-concept demonstrated in the early 1980's. Crane motion monitors were evaluated as part of enhanced spent fuel storage safeguards under the IAEA's TASTEX project.

STATUS

Developed technology

AVAILABILITY

Technology is available; however, there are no commercial suppliers.

COMMENTS

CRANE MOTION MONITOR

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Installed surveillance of SNM in storage.

TECHNOLOGY

Wireless alarm transmission of container handling (WATCH)

DESCRIPTION

The WATCH system provides a near-real-time indication of item movement. The main components of the system are sensor/transmitter (STX) packs that are firmly attached to the items to be monitored, and a receiver/controller unit (RCU) that monitors the STX packs. It is not possible to move the monitored item without moving the STX pack. Each STX pack contains a motion sensor that provides a signal to the transmitter circuitry whenever motion occurs, and this is relayed as an alarm message to the RCU. Under normal static conditions, each STX transmits periodic "state-of-health" messages to the RCU.

BACKGROUND

Sandia National Laboratory developed this system for use in domestic security applications so signal transmissions are not authenticated. (The AIMS system includes signal authentication.) The same system can be used to monitor movement of doorways, hatches, or valves. WATCH was tested at Rocky Flats and further development suggested.

STATUS

Work is continuing at SNL to develop a less expensive version with expanded capabilities (range, battery life).

AVAILABILITY

Presently available from commercial suppliers.

COMMENTS

STX packs on
SNM containers

Alarm on movement

WATCH

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Installed surveillance of SNM in storage.

TECHNOLOGY

Authenticated item monitoring system (AIMS)

DESCRIPTION

AIMS provides a near-real-time indication of item movement (or, if equipped with other than motion sensors, any other sensor output). The purpose of AIMS is to provide, over an authenticated radio frequency (RF) link, the status of a monitored item. The main system components are authenticated sensor/transmitter (ASTX) packs, that are firmly attached to the monitored item; and a receiver/processor unit (RPU) that monitors the ASTX packs. It is not possible to move the monitored item without moving the motion-sensing ASTX pack. Whenever an ASTX detects motion it immediately transmits an alarm signal to the RPU. Normal "state-of-health" messages are sent periodically. A single RPU can monitor up to 50 ASTXs. Information on ASTX events is stored in the RPU for later recall.

BACKGROUND

AIMS was developed at SNL. A predecessor system (WATCH) lacked signal authentication.

STATUS

AIMS is presently in use for international safeguards applications.

AVAILABILITY

Presently available

COMMENTS

AIMS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

On-site inspection at all SNM bulk-handling facilities.

TECHNOLOGY

Tamper indicating container and the authenticated item monitoring system (AIMS)

DESCRIPTION

On-site inspectors, conducting inspections at SNM bulk handling facilities, use verification standards and acquire material samples that for health and safety reasons must be stored in ventilation hoods or glove boxes. The inspector must be assured of the integrity of these standards and samples. This system is composed of two main elements; a secure container located within the glove box that contains the items to be secured, and a receiver unit located near the outside of the glove box. Information on container movement, access, and tamper attempts are transmitted from the secure container to the receiver via an authenticated radio frequency link. The receiver stores information on secure container events (including routine "state-of-health") for later inspector review. A single receiver can monitor 50 containers.

BACKGROUND

Developed by SNL. This system is a marriage of technologies tailored to address a specific problem.

STATUS

Technology has been demonstrated.

AVAILABILITY

Presently available

COMMENTS

SECURE CONTAINER AND AIMS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Installed surveillance systems at SNM-handling facilities.

TECHNOLOGY

Surveillance cameras (Film)

DESCRIPTION

A variety of surveillance systems have been developed and tested, primarily to record activity around reactor and reprocessing plant spent fuel storage pools. These include film camera systems. The "work horse" of the IAEA has been the Twin Minolta System. This system incorporates two Minolta movie-type cameras actuated at programmed time intervals. The cameras are redundant and are located in a tamper resistant/indicating housing. Semiautomatic scanners have been developed that respond to changes in the recorded images and store questionable frames for later review.

BACKGROUND

About 200 of the Twin Minolta Camera systems were in routine IAEA surveillance use in 1983; however, film is no longer supplied. Video systems (like MIVS) are replacing the Minolta systems.

STATUS

No longer supported by the manufacturer.

AVAILABILITY

COMMENTS

Surveillance cameras

SURVEILLANCE CAMERAS

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Installed surveillance systems at SNM-handling facilities.

TECHNOLOGY

Modular integrated video system (MIVS)

DESCRIPTION

The MIVS is a microprocessor-controlled CCTV system designed to operate in an unattended surveillance mode. The MIVS records video snapshots at selectable intervals ranging from one minute to ninety-nine minutes between recordings. Time and date information annotates the surveillance images. The primary MIVS components are the camera unit and the recording control unit (RCU). The camera may be located up to 30 meters from the RCU and video authentication is used to protect the interconnecting cable. The RCU incorporates a power supply, display module, dual redundant recorders, and a protective enclosure. MIVS uses facility power but can operate for up to three hours on internal batteries if external power fails. The MIVS has passed temperature, humidity, and shock testing. A MIVS video review station is available that process the video, authentication, and tamper indications for the inspector.

BACKGROUND

MIVS was developed by SNL, has been "red teamed", and demonstrated >99% reliability in IAEA tests. The IAEA is procuring MIVS to replace the twin Minolta film camera systems.

STATUS

Field commissioning tests began in 1988, and the first commercial production unit was installed in 1989.

AVAILABILITY

Presently available from a commercial supplier.

COMMENTS

Other video surveillance systems (COSMOS and TRTL) having similar features are also currently under development in Japan and Germany; however, MIVS is the present choice of the IAEA because of the features, reliability, and commercial availability.

MODULAR INTEGRATED VIDEO SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Short-term optical surveillance of areas containing items of safeguards interest.

TECHNOLOGY

Portable surveillance unit (PSU)

DESCRIPTION

The PSU is designed for situations where quick setup of an optical surveillance device is required. Two versions have been developed -- a single and a dual recorder version -- as a trade-off between reliability and size. Both versions are small enough to be carried to a facility by one person and rapidly placed into operation. The PUS may be connected to facility power, or can operate for about 24 hours on its own internal battery. The PSU can record up to 26,000 scenes at programmed time intervals from one to ninety-nine minutes between scenes. The camera is located in the same housing as the recording and control circuitry.

BACKGROUND

The PSU was developed at SNL as complementary work to the Modular Integrated Video System (MIVS). Both versions of the PSU were demonstrated at the 1989 annual meeting of the Institute of Nuclear Materials Management.

STATUS

The IAEA and EURATOM are assessing the PSU functional specifications.

AVAILABILITY

Presently available.

COMMENTS

**PORTABLE SURVEILLANCE
UNIT**

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Continuous surveillance of SNM storage vaults or shutdown facilities.

TECHNOLOGY

Digital image processing for materials control

DESCRIPTION

Digital techniques for analysis of images recorded by surveillance cameras are needed to detect tampering, movement, diversion, or misplacement of packages of SNM in storage. One such image processing system couples an IBM PC with a charge-coupled-device video camera and special software. The image processing software digitally subtracts each video image from a "reference" image obtained during initialization. Any changes, implying movement in the monitored scene, display as white areas in the difference display allowing rapid screening of the images for changes.

BACKGROUND

This digital image processing system is under development as part of the Los Alamos Safeguards and Security R&D program.

STATUS

An initial successful test of this technology was conducted in 1988 at the LANL Plutonium Processing Facility.

AVAILABILITY

COMMENTS

Since this technology detects changes in recorded images, it is most applicable to static storage areas.

SNM in storage

System records images
and processes for review

DIGITAL IMAGE PROCESSING

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Field verifiable general purpose sealing and identification system.

TECHNOLOGY

Cobra seal system (fiber optic system)

DESCRIPTION

The Cobra seal is a passive fiber optic seal, consisting of a loop of fiber optic cable secured with a seal assembly. The seal provides an indication of whether the fiber optic loop has been broken, or whether any attempt has been made to tamper with the sealing assembly. A unique seal pattern provides both identity of the seal, as well as the integrity of the seal loop. This unique seal pattern is formed when the seal is initially attached. Once the seal has been attached and a serrated cutting blade lowered to cut a random pattern in the sealing loop, a reference image of the seal pattern is recorded on a 2"X2" still video disk. When the seal is later verified, a new image is compared with the reference image. Changes between the newly recorded and the reference image indicate the seal tampering may have occurred. The main elements of the Cobra seal system include: seal assemblies, seal assembly tools, fiber optic cable, and image recording device, and an image display assembly.

BACKGROUND

This sealing system was developed at Sandia National Laboratory, and field tested by Euratom at a variety of locations. A similar fiber optic seal (the Brooks Fiber Lock) is also commercially available. The Brooks seal uses Polaroid to record the image, and does not cut fiber optic strands during assembly. The Cobra seal is generally thought to offer greater tamper resistance.

STATUS

In routine use by Euratom safeguards inspectors and under evaluation for use by the IAEA. Also routinely used by US OSIA. This seal has been "red teamed" and is available from a US vendor.

AVAILABILITY

Presently available.

COMMENTS

The Cobra seal appears to be the best general purpose, field verifiable safeguards seal.

ASSEMBLED COBRA SEAL

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Temporary sealing of SNM containers.

TECHNOLOGY

Adhesive seals

DESCRIPTION

This seal is made of paper or vinyl with a pressure sensitive adhesive backing. The paper seal is slitted so that it cannot easily be removed in one piece, and attempts to dissolve the adhesive will cause the ink to run. A similar seal is the frangible adhesive seal that consists of a plastic strip with adhesive marked with identifying information. If an applied frangible seal is removed, the adhesive and the information on it are removed and the word "void" appears. Adhesive seals are inexpensive. They could be useful where short-term containment needs can be met by sticking a seal on the surface.

BACKGROUND

These types of seals are widely used for many applications. They have been used for containment in SNM facilities, and by the US OSIA, but they have drawbacks.

STATUS

Widely used.

AVAILABILITY

Commercially available from a variety of vendors.

COMMENTS

One drawback of this type of seal is that they can be duplicated and can be removed and replaced. They are only useful for short-term applications or in cases where they are inspected frequently.

Adhesive seal

SNM container

**TEMPORARY APPLICATION
OF ADHESIVE SEAL**

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Tamper-indicating sealing and identification with laboratory verification.

TECHNOLOGY

Cup-and-wire seal (E-seal)

DESCRIPTION

Seals are used to identify and secure items. This type of seal consists of two cup-shaped pieces of brass sheeting. A wire may be threaded through holes in the item to be secured and through one cup of the seal; the wire ends are then knotted and the two cups fitted together to enclose the knot. The seals are identified by serial numbers. A unique, random pattern is applied to the inside of one or both cups and a photograph is kept for verification. Verification of the integrity and identity of a seal is a laboratory rather than a field task. These seals are also made with double caps where the second cap is metallic copper. A stainless steel version (the S-seal) is available for corrosive environments.

BACKGROUND

These seals are routinely used by IAEA and EURATOM safeguards inspectors, and within the US DOE complex.

STATUS

Widely used.

AVAILABILITY

Presently available.

COMMENTS

These seals could be made more useful by the development of a method for in field verification and identification.

Assembled Seal

CUP-AND-WIRE SEAL

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify the output of uranium enrichment facilities to confirm compliance with the negotiated HEU production limitation.

VERIFICATION REGIME

Sealing of UF₆ cylinders and process valves.

TECHNOLOGY

Shrink-tubing seal

DESCRIPTION

A clear plastic shrink-tube with a triangular dot pattern and another with a square numbered matrix are used to enclose the item to be sealed. When shrunk by heat application, the patterns become randomly arranged so that no two seals will have the same pattern. These are then photographed or otherwise recorded for later comparison. Any tampering will be revealed by misplacement of the random pattern.

BACKGROUND

This seal system was developed at Brookhaven National Laboratory and field tested by the IAEA primarily for sealing cylinders of UF₆.

STATUS

The shrink-tubing seal experienced limited use by the IAEA; however, the US OSIA is using a comparable shrink tubing in limited applications.

AVAILABILITY

Presently available from limited commercial suppliers.

COMMENTS

Valve

First shrink
tube applied

Second shrink
tube applied
for unique ID

SHRINK TUBING SEAL

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Recording of access to sealed containers.

TECHNOLOGY

VACOSS electronic sealing system

DESCRIPTION

VACOSS is a reusable on-site verifiable electronic seal designed to register (but not necessarily prohibit) access to material in the sealed container. It uses an optical fiber cable for the sealing. Opening and closing of the seal are recorded with times and dates in a battery powered microchip which is contained in the seal. This information can be obtained from the seal using an adapter box, either on-site or remotely. The system is designed to operate under various extreme conditions, such as temperature variation between -20 C and 75 C.

BACKGROUND

VACOSS was developed at the Nuclear Research Centre Julich under an agreement with IAEA and has been tested extensively.

STATUS

After several years of development, the VACOSS technology has been made available for commercial production and routine use by the IAEA and EURATOM.

AVAILABILITY

Presently available.

COMMENTS

VACOSS SEALING SYSTEM

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.

VERIFICATION REGIME

Sealing and identification of fuel assemblies with field verification.

TECHNOLOGY

Ultrasonic seals

DESCRIPTION

One version of these seals contains a random coil of stainless steel wire from which a unique acoustic signature can be acquired. This version, developed by AECL of Canada, is known as the ARC seal. JRC-Ispira has likewise developed a seal comprised of stacked washers brazed together. This seal is known as the VAX seal. The signature from both seals can be recorded upon installation and checked at any time for verification of the identity and integrity of the seal. The acoustic signal is acquired by an ultrasonic transducer. An electronic seal pattern reader (SPAR) processes and records the signal in digital form and automatically determines the correlation between measured and reference responses.

BACKGROUND

The seal designs are based on work carried out at Ispira and AECL. The SPAR readout unit was developed by SNL. The ARC/SPAR system has been accepted for routine use by the IAEA.

STATUS

IAEA and the Canadian Safeguards Support Program have reported a successful 16 month trial of the ARC/SPAR system at a CANDU reactor. The ARC/SPAR system was used to seal underwater containers of spent fuel. The Joint Research Centre at Ispira and SNL are currently developing applications of the VAX/SPAR seal system to containment of fresh MOX fuel for PWRs and BWRs. A joint AECL/SNL/JRC/IAEA program to develop a universal ultrasonic sealing system is being considered.

AVAILABILITY

Presently available technology; the ARC/SPAR system is available in limited quantities.

COMMENTS

ULTRASONIC CAP SEAL

VERIFICATION REQUIREMENT

Adequately safeguard SNM in the civilian nuclear cycle to preclude the diversion of significant quantities to weapons purposes.
Verify that declared prohibited facilities are shutdown and remain unused.

VERIFICATION REGIME

Real-time monitoring of equipment status.

TECHNOLOGY

Remote continual verification system (RECOVER)

DESCRIPTION

RECOVER was an integrated system for continually monitoring the integrity of inspector-placed seals and cameras deployed by the IAEA at nuclear facilities. As envisioned, RECOVER polled each device to determine its operating status (working or not working) and recorded the results. The recorded status information was transmitted in code to a distant command center via phone line when the RECOVER unit was polled. The system consisted of units developed to determine the status of the seals or devices; a microprocessor-based unit that controlled the collection of device status information, responded to communications requests from the command center, and performed self verification tasks; and communications equipment to provide for coded phone transmissions.

BACKGROUND

Proposed in 1978 by ACDA to assist IAEA safeguards. Some prototype hardware and testing was performed as part of the Program for Technical Assistance to IAEA Safeguards (POTAS) coordinated through BNL. RECOVER was never tested in a "full-up" mode.

STATUS

ACDA eventually transferred the RECOVER technology to JAERI in Japan. The JAERI system is known as "Transceiver". Through a recent agreement between ACDA and JAERI, a demonstration of the transceiver system is planned.

AVAILABILITY

Technology is available.

COMMENTS

THE RECOVER SYSTEM

THIS PAGE INTENTIONALLY LEFT BLANK

END

**DATE
FILMED**

8 / 26 / 92