A BRIEF HISTORY OF NDA AT THE IAEA

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ABSTRACT

Nearly 30 years ago, the first portable nondestructive assay instrument, a SAM-II, was brought to Vienna for IAEA consideration. This initial foray into the usage of nondestructive assay (NDA) as an independent assessment tool has materialized into one of the important tools for IAEA inspections. NDA instruments have several inherent advantages for inspectors; their measurements generate no radioactive waste, provide immediate answers, do not require specialized operators, and can be either taken to the items to be measured (portable instruments), or the items for measurement can be brought to the instruments, such as can be applied in on-site IAEA laboratories or off-site IAEA lab at Siebersdorf.

The SAM-II was a small, lightweight, battery-powered, gamma-ray instrument used for uranium enrichment measurements. It was also found to be useful for locating nuclear material, distinguishing between uranium and plutonium, and determining the active length of items like fuel pins. However, it was not well suited for determining the amount of bulk material present, except for small containers of low-density materials. A 6-sided neutron coincidence counter, easily disassembled so it could be shipped and carried by airplane, was developed for bulk measurements of plutonium. The HLNCC (High Level Neutron Coincidence Counter) was immediately useful for quantitative measurements of pure plutonium oxide. However, the IAEA had to make a trade-off between the ease of use of NDA instruments on-site, and the problems of obtaining small samples for shipment to an independent lab for more accurate analysis. NDA does not create radioactive waste, so as waste handling has become more cautious and more regulated, NDA looks better and better.

After acceptance of NDA by the IAEA for routine use, the follow-up question was naturally, “How much better can this measurement be made?” The Program for Technical Assistance to IAEA Safeguards (POTAS) supported multiple and varied efforts in this direction, such as improving both the plutonium isotopic distribution measurement and the multiplicity counter, so that the assays can be performed on any plutonium samples instead of only pure oxides. Advances have also been made on uranium bulk measurements by the development of the active well coincidence counter.

Meanwhile, several large bulk-handling facilities have been coming on line under IAEA safeguards. These facilities require full-time inspectors to be present whenever the plant is operating. The IAEA requested help so that measurements can be made even when inspectors are not present. The evolution and success of unattended NDA has been responsible for the capability of the IAEA to monitor large bulk-handling facilities without substantial increase in inspection effort. The integration of NDA with containment & surveillance measures and automation has been crucial to reducing inspection manpower. These systems have developed to the point where the IAEA can make credible conclusions on large high-throughput plants such as mixed-oxide (MOX) fuel fabrication or reprocessing plants.
INTRODUCTION

Nearly 30 years ago, the first portable nondestructive assay instrument, a SAM-II, was brought to Vienna by Los Alamos National Laboratory (LANL) for IAEA consideration. This initial foray into the usage of nondestructive assay (NDA) as an independent assessment tool has blossomed into one of the important tools for IAEA inspections. While LANL-developed instruments have played the dominant role in NDA measurements for international use, LANL is not the only development laboratory supporting international inspections and audits of nuclear material; other laboratories have also made significant contributions.

NDA instruments have several inherent advantages for inspectors. By providing inspectors with immediate results after a few minutes of measurement, they radically changed how inspectors and facilities interact. Additionally, these measurements generate no radioactive waste, require minimal sample preparation and handling, and can be performed by modestly trained operators. As NDA techniques have developed, one observes that either the instrument is taken to the sample or vice versa.

THE LATE 70s—A BEGINNING

One of the most influential activities of the US support program is also almost one of the longest running. A large number of Cost Free Experts (CFEs) has supplied the MEA with specialists in many technical specialties. The IAEA has benefited from this supply of expertise without having to commit to an internal training and development program. Consequently the IAEA has been able to transition to innovative technology or ideas faster than would otherwise be possible. By temporarily trading their expertise for an opportunity to live abroad for a few years, experts in NDA, electronics, statistics, software, procurement or property management, and neutron or gamma-ray physics have enabled the Agency to change and improve.

A second activity of the US Support Program to the IAEA began in the early years and also had major impact on IAEA operations and success. US initiatives in the procurement of NDA instruments, support of testing and evaluation, training, and purchasing of large numbers of successfully utilized instruments have enabled the IAEA to begin and to continue to obtain assay results during inspections. This has, in turn, permitted assessment and drawing of preliminary conclusions before an inspector leaves a site, rather than causing a several-week wait for results, thereby avoiding the possibility that time will dilute the questions, conclusions, and resolution process.

A third major contribution was the training funded by the US support program (Fig. 1). This began with training for every IAEA inspector, but has grown to include several other types including maintenance training, system installation, and even training in the operation of unattended monitoring systems.
Most of the instrument families now seeing heavy use saw their introduction in this decade. The high level neutron coincidence counter (HLNCC) shown in Fig. 2 was introduced for quantitative measurements of bulk plutonium based on neutron coincidence counting. Cerenkov glow instruments were assessed for qualitative identification of spent fuel, as were gross gamma and gross neutron counter/timers. The active well coincidence counter (AWCC) shown in Fig. 3 was introduced for quantitative measurements of bulk uranium based on active neutron coincidence counting. Reactor power monitors based on gross radiation measurements were assessed and began to see routine use. Plutonium isotopes based on passive measurements with high-resolution gamma-ray detectors allowed the IAEA to be independent of facility declarations to interpret neutron measurements. For uranium, enrichment measurements began with low-resolution detectors. When interferences limited the applicability of those measurements, specialists added high-resolution capability to resolve difficulties with minor isotopes.
Calorimeters were evaluated, but never quite gained acceptance for IAEA use, possibly because they require longer counting times more consistent with destructive assay (DA) measurements. The gamma-ray and neutron based measurement systems did gain in popularity. Inspector reliance on portable measurement tools had begun. Portable NDA drastically changed the way facility inspections were carried out. The addition of inspector measurement capability allowed rapid resolution of certain questions without sampling, shipping to an off-site lab, and waiting for the lab results.

**EARLY 80S–PERIOD OF RAPID GROWTH**

The next several years saw rapid growth in the deployment of nondestructive assay instruments. The US support program continued to supply CFEs, instruments, and training. The IAEA inventories of instruments proliferated almost into confusion, with many varieties of similar but not interchangeable components.

Several NDA-measurement CFEs spent a year or more in Vienna, training inspectors how to use instruments, developing procedures, and building infrastructure to maintain & deliver working instruments to the inspectors. Other CFEs helped the IAEA select standardized components and develop inventory procedures and standardized instrument preparation and calibration for field use.

The addition of the portable K-edge densitometer (Fig. 4) appended specific measurement hardware to the portable multichannel analyzer (PMCA) for an innovative purpose. The concept was that the IAEA would bring a portable version of a facility instrument to a site. If an arbitrary sample, measured with both instruments, yielded the same result, the IAEA would accept the facility measured values for its purposes. This instrument was first used at the Tokai-mura reprocessing facility in Japan.

This period saw the increase in reported nuclear materials begin to exceed the IAEA capability to apply its traditional approach. The IAEA was faced with ever increasing demands on inspection resources. One solution brought forward to address this growing problem was unattended monitoring. A precursor to modern multi-sensor unattended monitoring systems was the gamma-ray and neutron detector electronics (GRAND) instrument. This series of gross gamma/gross neutron monitors was developed and placed into Canadian deuterium-uranium (CANDU) reactors to
monitor fuel movements. While these deployments were not considered to have complete facility coverage, they did supply IAEA inspectors with considerable information about the facility activities during the inspector’s absence.

Fig. 4. Los Alamos engineer Leo Cowder demonstrates use of the portable K-edge densitometer.

A new major thrust area for the IAEA began to evolve about this time. The Agency began to put lots of effort into performance values—databases of results to compare measurement precision and bias across different material types, inspectors, instruments, and facilities. Innovations such as the concept of cross-calibrating detector families, calibrating with fewer standards, calibrating with Monte Carlo neutron and photon transport code (MCNP) calculations, and adaptation of the available tools to a wider set of measurement problems were introduced.

Cross-calibration described the procedure by which one instrument was carefully calibrated with several sets of calibration materials. Then similar instruments were manufactured under stringent controls to duplicate the initial instrument’s performance. These copies were then shown to have similar performance through use of a small subset of the original calibration materials, allowing the original calibration to be adapted to the copied instruments.

European contributors led the primary efforts on instrument performance values; the US program participated and provided support to specialists developing the data set.

One realization from this time frame was that the IAEA learned that certain benefits accrued from specialization. Some inspection personnel were better than others at certain skills, and inspection efficiency could be improved if individuals were allowed to specialize in certain areas; procedures,
neutron measurements, plutonium isotopes measurements, accounting audits, and DA are a few examples.

This period ended with the selection of the LANL-developed, Davidson engineered and mass-produced PMCA as the IAEA tool of choice for several gamma-ray measurements. (See Fig. 5.) The PMCA was one of the earlier R&D efforts that shared funding across several sponsors, who all recognized the benefits of this concept. The PMCA, used for U enrichment measurements, measurement of Pu isotopes, and bulk measurement of certain items meeting stringent specs, such as materials test reactor (MTR) fuel plates, was the first portable, battery powered instrument that was transported to the samples under inspector control. It was the first truly portable gamma-ray spectroscopy system that included signal processing electronics, analysis programs, and a built-in computer. This new instrument created drastic change in IAEA capabilities and inspectors and procedures quickly adapted to its innovative capabilities. Ease-of-use lead to it being an IAEA workhorse for nearly 15 years.

**Fig. 5. Chris Bjork instructing two young IAEA inspectors participating in a training exercise at Los Alamos for the Davidson PMCA.**

**LATE 80S–FOCUS ON STANDARDIZATION**

Over the next few years the US support program continued to supply CFEs, instruments, and training. The concept of a standard “tool kit” for the inspector was tried. Every inspector had his or her laptop, and it contained software for all of the NDA instruments, sampling plans, and reports for every facility type. Inspector training was standardized and increased. NDA courses became more rigorous, more complete, and more extensive.

While the standardization helped in some ways, it also revealed areas for further improvement. Help arrived in the form of further control of inventories of instruments, spare parts, standardized maintenance, and reporting of inspection results. As inspectable nuclear material stocks continued to grow in the Western world, zero-growth budget policies placed more demands on inspection resources that were not able to increase at similar rates. Financial constraints effectively placed a limit on the amount of inspection and audit activity for monitoring activities involving nuclear material.
A natural development at this stage was the growth and maturing of unattended activities. How could the IAEA verify that only authorized activities were occurring when an inspector was not on site? Application of tamper-indicating devices had limitations, for example, the facility could not use the sealed item or facility until an inspector returned. Cameras had other limitations, such as not being capable of identifying the contents of containers. Reliability problems and data loss from component failures were additional difficulties to be addressed. The first step toward addressing such issues was monitoring radiation levels; this was rapidly followed by creating ways for the occurrence of reliable NDA measurements when an inspector was not present and by installing other sensors such as video cameras for surveillance of activities.

Unattended NDA monitoring systems were installed in the Japanese robot automated Plutonium Fuel Production Facility (PFPF) in 1987 and are still in use today (Fig. 6). These unattended NDA systems give complete coverage of all plutonium usage throughout the facility. Unattended NDA measurements cover MOX powder receipt through to the output fuel assemblies. Other attended measurements deal with in process materials, glove box holdup, and waste and scrap. These systems have been estimated to reduce inspection efforts by a factor of five or more.

![Fig. 6. Plutonium Canister Assay System, Installed in the Plutonium Fuel Production Facility.](image)

It became apparent that the IAEA Vienna office had some severe limitations, one being that essentially no radioactive materials were allowed on the premises. Routine use of NDA equipment required daily use of measurement control standards, frequent need to access calibration materials containing significant quantities of nuclear material. Development of Performance Laboratory (PERLA), the NDA support facility at JRC-Ispra, Italy, followed. PERLA was designed as a user facility similar to those in the nuclear or high energy physics community, where personnel from many locations could bring training seminars and instruments and could use lab facilities and share well characterized calibration materials. This development was driven, in part, by the high cost of fabricating, storing, and safely using calibration materials. Of course, other labs supplied facilities and calibration materials too, among them LANL. For a period of time, all neutron counters were inspected and calibrated at LANL before shipment to the IAEA.
MID-90S–INTEGRATED SYSTEMS FOR INSPECTION EFFICIENCY

This time period brought a continuation of CFEs, instruments, unattended system installations, and training. Technology advanced quickly, the IAEA inspectors hard-pressed to keep up with the ever-expanding choices. CFEs helped sort through the choices, evaluate proposals, and implement the selected technologies (Figs. 7 and 8).

Fig. 7. Los Alamos software developer Shirley Klosterbuer training personnel on the unattended system installed in Aqtau BN-350 reactor.

Fig. 8. Los Alamos scientist Merlyn Krick explains neutron coincidence counting at another training seminar at Los Alamos.

The mid-90s saw application of traditional instruments to novel material types or flows, refinement of unattended data collection, improvement in data review tools, incremental improvement in detectors, and new approaches such as alternate nuclear materials (ANM) or Curium balance. Benchmark data for large reprocessing plants was collected to understand measurement possibilities.

Simulation to model neutron counter behavior increased through the use of LANL’s MCNP and other transport codes. Optimal detector size and placement, as well as error propagation and prediction, were determined.
Automated software for review was also developed, allowing the inspector to easily reconcile facility declarations with integrated safeguards monitoring system data. This period brought growth of unattended monitoring systems, from individual radiation detectors and cameras to 10 or more radiation detectors integrated with video surveillance and sometimes with other sensors in one integrated system. To support this integration, better data collection tools, data archiving approaches, and networked instruments were developed.

The 1997 integrated system installed at the Rokkasho Spent Fuel Receipt and Storage facility (Fig. 9) integrated radiation sensors with video tracking into facility operations, while decreasing IAEA inspection time by more than factor of 10. Similarly, the 1998 monitoring system installed in the fast breeder reactor in Aqtau, Kazakhstan reduced IAEA manpower by a factor of 4. The cost of the system in Kazakhstan was shared between several DOE offices and International Safeguards Program Office (ISPO), continuing a long tradition of teamwork to get the job done well. The year 1999 saw the installation of a remote NDA system in the PFPF facility. This system transmits NDA data to the IAEA Tokyo Regional Office (TRO) allowing inspectors to quantitatively reconcile plutonium mass without traveling to the facility.

![Fig. 9. LANL engineer Mark Abhold installs an integrated monitoring system with IAEA inspector Syed Azmi at the Rokkasho Spent Fuel Facility.](image)

**CURRENT ACTIVITIES**

NDA developments still are important needs for the IAEA. NDA activities currently funded or recently funded under the US support program include:

- New AWCC cross-calibration
- Evaluation of CdZnTe detectors
- Upgrade personal computer version of Fixed Response Analysis Method for Pu-Isotopes for gamma measurements of UF₆ cylinders
- Development of procurement specifications for 10-atmosphere ³He detectors
- Development of a new preamplifier for ³He detectors
- MCNP studies of neutron detector design and placement
- Software, for both instrument operation and data review
- Repairs of instruments in current use in facilities
- Updating and improving manuals
- Advanced Multiplicity Shift Register development
- Technician training for instrument maintenance and repair
- Upgrade Cascade Header Enrichment Monitor
- Study verification methods for U diffusion plants
- Assist in installation of unattended monitoring at the Aqtau reactor
- Customize hybrid K-edge software for SAL
- Ethernet instrument connectivity study
- Upgrade of FORK detector software
- Mini-Gamma-Ray and Neutron Detection Electronics instrument commercialization

CONCLUSIONS
The US support program has played a significant role in identifying IAEA needs and developing NDA equipment and techniques that address these needs. ISPO has helped identify measurement needs that could be addressed by NDA. Not only has the US support program funded development, but POTAS has also funded many purchases of NDA equipment for IAEA use, CFEs for implementation, and training programs for IAEA inspectors.

POTAS will continue to be the largest national program of support to the IAEA and the NDA role will continue and perhaps increase, because it focuses on a signal from the material of interest, generates no waste, and does not alter the item being measured.

The POTAS program will continue to cooperate to share funds from several sponsors, and as appropriate, to develop and deploy nondestructive tools that enhance and improve the ability of the IAEA to verify authorized use of special nuclear materials.

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