# Operational Experience with an Imaging Passive/Active Neutron System (IPAN™) in a Mature Production Application to Perform WIPP Certified Non-destructive Assays

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## ABSTRACT

BIL Solutions Inc. have deployed and operated an Imaging Passive/Active Neutron System (IPAN™) System at the Savannah River Site (SRS) in South Carolina for the purpose of performing non-destructive assays on contact handled transuranic (CH-TRU) waste in 55-gallon containers. During the four-plus years of operation (May 2001 through August 2005), a vast amount of experience has been gained, with approximately 8950 waste containers assayed. This experience has provided the knowledge base for the evolution of improvements in the assay technique and instrument maintenance and troubleshooting. Additionally, operational experience provides for very reliable characterization of the robustness and applicability of this assay technique for a wide variety of waste streams and provides for assessment of the achievable production output capabilities over a long period of time in a production environment.

The assay technique combines passive/active neutron data with gamma energy analysis (GEA) data and acceptable knowledge (AK) data to provide Waste Isolation Pilot Plant (WIPP) compliant quantification of the required nuclides within the waste. These data are incorporated through system software, which automate the data analysis process. However, due to the complex nature of NDA and the potential for a wide variety of interferences, each analysis is reviewed by an Expert Analyst (EA). The software allows the EA to interact with the data analysis process to provide regulatory compliant and defensible results. This technique has evolved with time as a vast array of waste and isotopic compositions have been encountered

During 1555 days from the beginning of production operations, the system maintenance log indicates 63 days of downtime due to hardware problems. This translates to an operational availability of 96%. Given the extensive length of time represented by this availability data, 96% availability would represent a very reliable estimate for future applications. Additionally, evolving improvements in troubleshooting techniques and stocking of spare parts could improve the availability. The 8950 production assays performed at SRS falls far short of predicted system throughput, even with allowance for performance of non-production assays such as Quality Assurance (QA) / Quality Control (QC) and WIPP Performance Demonstration Program (PDP) assays. It should be noted that production was significantly altered by site constraints and interruptions in availability of containers.

The overall assessment of the instrumentation in conjunction with the assay technique is that this method has a wide range of applicability over a wide range of waste streams. The capability of the EA to interactively interact in the data analysis provides for successful analysis of a wide variety of exception conditions and/or isotopic compositions. The instrument has demonstrated reliable and regulatory compliant operation over a long period of production operations. This assay technique should be suitable

for future applications for most TRU or low-level (LLW) waste streams, including remote handled (RH) waste.

## INTRODUCTION

BIL Solutions Inc. have deployed an IPAN™ System at SRS for the purpose of performing NDA on 55-gallon containers of dry heterogeneous TRU waste. Productions operations, commencing in May 2001, were preceded by a several month period of instrument installation, calibration testing, total measurement uncertainty (TMU) assessment, assessment of lower limit of detection (LLD), and development of procedures and documentation to satisfy all Site and WIPP requirements. Since the beginning of production operations, the System has continued to provide continuous capability to perform WIPP certified assays meeting all Site and WIPP requirements including audits and participation in the WIPP PDP program, where "blind" assays are performed to meet specific accuracy and precision requirements on standards contained within surrogate waste containers.

The assessment of instrument capability was initially demonstrated through the calibration testing, TMU and LLD assessments performed prior to production operations. These assessments demonstrated the capability of this technique to meet all WIPP requirements for the specified waste streams, including an LLD below the required 100 alpha nCi/g (TRU isotopes). Since May 2001 a vast knowledge base has been accumulated through operations and the completion of 8950 production assays on the SRS waste streams.

The purpose of this paper is to present: (1) an overview of the NDA technique used, (2) system operating ranges and capabilities, (3) technique improvements resulting from operational experience, and (4) an overall assessment of applicability to varying waste characterization applications.

## OVERVIEW OF THE NDA TECHNIQUE

The NDA technique consists of conducting three distinct NDA measurements and combining the data from these measurements along with additional AK as required to provide the final reportable characterization results. The NDA measurements comprise a passive neutron measurement, an active neutron measurement and a gamma energy analysis measurement.

Passive neutron counting consists of measuring the intrinsic fast neutron emission from the waste. The passive neutron coincidence counting technique exploits the fact that neutrons from spontaneous fission are emitted essentially simultaneously, whereas background neutrons and neutrons emitted from (alpha,n) reactions are non-coincident. Passive neutron measurements are used to quantify even isotopes of plutonium and other spontaneous neutron emitters [1].

The active neutron measurement consists of measuring neutron-induced fission events in fissile material such as Pu-239 within the waste. Neutrons from an interrogating source are introduced into a measurement chamber consisting of moderating and shielding materials. These neutrons induce fission events in fissile material, giving rise to the emission of secondary fast neutrons. Various techniques are used to maximize the sensitivity to secondary neutrons, while minimizing the signal from the interrogating source. One widely used method is the differential die-away (DDA) technique. Short pulses of fast neutrons from a neutron generator are injected into the measurement chamber. This gives rise to a thermal neutron flux, which persists for a few milliseconds. Fast neutrons arising from the induced fission events are then counted using fast neutron detector packages embedded in the chamber walls [1].

The passive and active neutron measurement data are processed through a mathematical imaging algorithm. The purpose of the imaging algorithm is to reduce the measurement uncertainty due to source positioning variation within the waste containers. The result is improved sensitivity and regulatory compliant precision and accuracy of results [2].

An example IPAN™ System is depicted in Fig. 1.


Fig. 1. IPAN™ system

Gamma Energy Analysis consists of analyzing gamma spectra to quantify specific isotopes or to ascertain mass fractional data for those isotopes with characteristic photo peaks above the lower limit of detection. Quantification of gamma-emitting isotopes requires establishing an efficiency curve, which accurately corrects for the sample matrix attenuation of the photo peaks. The mass fractional data, however, may be obtained by mathematical models, which establish a "relative efficiency curve" for the waste container by utilizing the branching ratios of isotope(s) with multiple peaks and the detector efficiency characteristics.

AK data consists of additional knowledge regarding the waste, that satisfy regulatory requirements for "acceptable" and that can be utilized to assist in the quantification of reportable radioisotopes within the waste. An example of AK would be information on the origin of the radio isotopic species in the waste that would allow the quantity of a specific isotope with no characteristic photo peaks to be correlated from the measured quantity of other isotopes in the waste.

The combining of the data from both neutron measurement techniques (IPAN™), the gamma energy analysis (GEA) and the AK data is a complex set of rules and mathematical formulae that are developed for specific waste streams with specific measurement conditions and specific regulatory requirements for characterization. The IPAN™ software performs the vast majority of the data manipulation. The Expert

Analyst (EA) reviews each analysis and supervises the calculation to incorporate AK and selects the most appropriate analysis method for the waste container. The EA employs experience and professional knowledge of physics principals and NDA to arrive at defensible mechanisms to achieve the final results. As will be discussed below, these techniques have been greatly improved through operational experience at SRS.

## SYSTEM OPERATING RANGES AND CAPABILITIES

The System employed at SRS currently has a verified operating calibration range of 0-120 grams Weapons Grade plutonium. The upper limit was primarily limited to this range, because there were no available sources to verify the calibration to levels above 120 grams. More recently, additional plutonium sources have become available and efforts are proceeding to validate and extended range to approximately 200 grams.

The Lower Limit of Detection (LLD) for the System was determined during the pre-operations phase at SRS. The LLD is matrix specific and ranges from approximately 600-2100 µCi plutonium (7.5 – 26.3 mg) over the range of dry heterogeneous matrices. For typical container masses within these matrix ranges (based on masses of surrogate waste containers) these LLD values translate to minimum detectable concentration (MDC) values of approximately 18-43 nCi/g. These MDC values may be considered typical for an IPAN™ System employed to assay 55-gallon drums. It should be noted that in actual waste drums, the MDC could be significantly higher if the drum is of much lower than typical mass value (e.g. partially filled). Also the MDC values are somewhat higher (approximately 90 nCi/g) in matrices such as sludge, which have higher neutron moderation characteristics. Additionally, MDC is a function of ambient background levels. Therefore, actual values are dependent on the environment in which the System is deployed. Higher elevations above sea level and locations very near waste storage or staging areas are examples of conditions that can adversely affect LLD values.

The total measurement uncertainty is also an assay-specific value that is calculated from specific assay parameters using complex error propagation formulae. In general, the relative uncertainty (%error) increases as the plutonium concentration decreases. At levels well above 100 nCi/g the uncertainty is normally in the range of 30%. At levels very near 100 nCi/g, typical uncertainty values range from 40-80%. It should be noted that the higher values of relative uncertainty occur only at very low plutonium levels. Therefore, the summation of plutonium quantities over a large number of drums in a TRU waste stream, to determine total plutonium loading, would have a propagated uncertainty in the range of 30%.

The System at SRS was in a continuous production operations mode from May 2001 through August 2005. Over a period of 1555 days the System log indicated 63 days that the System was down due to hardware problems. This translates to a System availability of 96%. During this time, a vast amount of experience has provided for improved troubleshooting techniques and for a spare parts list that includes any of the components that are likely to fail. It is, therefore, most probable that future availability will exceed 96%.

The total number of production assays that have been completed in 4 years plus of operation is 8950 waste containers. The 8950 production assays performed at SRS falls far short of predicted system throughput, even with allowance for performance of non-production assays such as QA/QC and WIPP Performance Demonstration Program (PDP) assays. It should be noted that production was significantly altered by Site constraints and interruptions in availability of containers. The System has been operated on a variety of weekly shift schedules as dictated by Site constraints. The most common daily shift consisted of 12 hours. On a typical full day of operation, the average daily output averages about 20 containers per day. This figure is probably the most meaningful expression of expected output from the

System, whereas the 8950 total output in excess of four years is primarily influenced by Site shutdowns and other Site or contractual constraints.

## TECHNIQUE IMPROVEMENTS RESULTING FROM OPERATIONAL EXPERIENCE

Over the last four years plus of operations at SRS (May 2001 through August 2005), a wide variety of waste and isotopic compositions have been assayed with the IPAN™ System. A number of improvements have been made in the methodology for performing EA. At SRS, these improvements have been incorporated into the Site procedure under which the EA is performed. Several examples of improvements to the EA technique are cited below.

Many of the waste streams at SRS are dominated by Pu-239 which is seen as the predominate contributor to the active neutron signal. The passive signal in these streams is dominated by Pu-240. While the ratio of Pu-239 to Pu-240 is variable in these streams, the range is limited. Specific SRS experience has provided a typical range over which the ratio of active to passive signal levels will vary in these waste streams. The EA uses this range to check specific assays for a ratio that falls outside that range. This serves as a flag to the EA that either the active or passive signal may be spurious, due to interference.

A significant number of the waste containers assayed at SRS contain high quantities of plutonium fluoride, which produces very large numbers of neutrons from (α, n) reactions. In some cases, the signal is so large with respect to the neutrons from spontaneous fission, that they create a positive bias in the passive neutron coincidence measurement, thereby invalidating the passive analysis. In such cases only the active neutron signal can be considered valid. The EA uses the presence of any of the three plutonium fluoride characteristic gamma peaks as indicators of potential presence of neutron interference from plutonium fluoride.

The presence of Cm-244, which has a very large spontaneous fission yield, is also present in some of the waste at SRS. As this would result in an increase in the passive coincidence signal, the EA must determine if Cm-244 is present. The Cm-244 emits a gamma that is at the same energy as one of the Pu-238 gamma peaks. When this peak is detected and the most abundant Pu-238 peak is either not present or is present at a level significantly less than the Pu-238 branching ratios would dictate, the presence of Cm-244 can be deduced. Comparison of active and passive data is another way that the possible presence of Cm-244 can be deduced.

WIPP requires the reporting of Sr-90, which has no neutron or gamma emissions (is silent to NDA techniques). The AK at SRS has been used to derive the Sr-90 from the Cs-137 quantification.

The examples above are indicative of a complex set of rules and mathematical formulae that are used to combine data from IPAN™, GEA and AK to resolve all of the WIPP reporting requirements. At SRS the resolution involves EA supervision to arrive at the final reported quantities. Future applications for IPAN™ Systems will utilize enhanced software that has been developed to automate the application of most of these complex rules and formulae. The software provides flags for the EA, when rare exception conditions require off-line EA review. The new software provides the flexibility to address a wide variety of waste streams.

Specifically, the software provides a specified format by which AK information is interfaced to the software as an ancillary file. Additionally, supporting software allows for the entry of specific AK data for each waste stream into convenient spreadsheet tables. After these have been entered, the software formats and produces the ancillary file for that waste stream. The AK data in these files includes all potential gamma-ray interferences that can be derived from the suite of isotopes present in the waste stream. The software automates the process for quantifying each isotope from correlating either the active or the passive signal to either the measured gamma mass fraction or the AK mass fraction.

This first implementation of the expanded software technique was implemented in the Multi-Purpose Crate Counter (MPCC). This System was developed to perform assays on Weapons-Grade plutonium waste contained in large waste crates at the Rocky Flats Environmental Technology Site (RFETS). The System performed production WIPP certified assays and LLW/TRU sorting of waste in these containers between 2002 and 2005[3,4].

## SUMMARY OF EXPERIENCE AT SRS

The IPAN System at SRS has performed non-destructive assays on approximately 8950 drums of CH – TRU waste. A vast amount of operational experience has been gained in relation to the assay technique, on-demand reliability and troubleshooting. The system's long-term stability has therefore been proven in a mature production environment. The operational availability of the system was 96 % over a period of 4 years.

Over the period of 2001 – 2005, the system has provided the continuous capability to perform WIPP certified assays in compliance with Site and WIPP requirements including audits and participated in the PDP program. The IPAN has met all of the regulatory requirements for accuracy and precision on standards contained within surrogate waste containers.

The capability to selectively integrate 3 distinct measurements (active neutron, passive neutron and gamma energy analysis), while incorporating waste stream specific AK has proven to be a very robust methodology for characterization of a wide variety of TRU waste streams. This methodology has significantly benefited from the experience with the IPAN System at SRS.

## REFERENCES

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