SWEPP ASSAY SYSTEM SOFTWARE – AN UPDATE

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ABSTRACT

The development of a new software package to control data acquisition and perform data analysis for a Passive/Active Neutron Assay system was reported at this conference in 1994. The software has undergone additional development including improvements to the user interface, additional data integrity checks and support for a shift register coincidence analyzer. An overview of this additional work is presented in this report.

INTRODUCTION

The development of a Microsoft Windows® software package for use with the Passive Active Neutron (PAN)1 assay system at the Stored Waste Examination Pilot Plant (SWEPP) at the Idaho National Engineering Laboratory’s (INEL) Radioactive Waste Management Complex (RWMC) was described2 at this conference in 1994. The PAN system is the primary nondestructive assay instrument used at SWEPP to determine the plutonium content of transuranic (TRU) waste packaged in 55 gallon drums. The software package is referred to as the SWEPP Assay Software, or simply “SAS”. This paper presents an overview of enhancements that have been made to the SAS package and some “work in progress”.

The initial release of SAS, Version 1.0, was installed at SWEPP in January of 1994 and replaced a FORTRAN program called “NEUT2”. The NEUT2 code was originally developed at the Los Alamos National Laboratory and extensively modified by a commercial supplier of PAN systems and personnel at the INEL. The second release of SAS, Version 2.0, was put into routine operation in May of 1996. Version 2.0 contained enhancements to the user interface, additional data integrity checks, an algorithm to correct for the presence of $^{235}$U, a revised analysis report format and corrections to several operational and technical problems that were discovered during approximately one year of production use. Work is currently in progress on a new SAS version that will contain support for a shift register coincidence analyzer and additional analysis capa-
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abilities. If time permits, it will be converted to "32 bit native mode" for WindowsNT®. This version is scheduled to be installed at SWEPP in March of 1997.

The original object-model design of SAS has been retained with new objects added where necessary to accommodate additional functional requirements. The use of configuration files has been expanded to allow extensive customization of the program's behavior without requiring modification to the underlying coding instructions. Every effort has been made to keep the software highly maintainable yet flexible and a significant amount of effort has been expended on documentation. The documentation consists of a set of formal documents and extensive comments within the C++ source, header and configuration files.

DATA INTEGRITY CHECKS

Examination of historical data from the PAN system revealed many instances of malfunctioning detectors, suspiciously high counts from one or more detector banks (indicating that the drum rotator was possibly not functioning) and bad background data.6 The NEUT2 program included no checks on data integrity; it was assumed that the user would examine the data and determine whether or not it was valid. This type of approach does not work in a "production environment" such as SWEPP; the operators tend to just assume that any computer generated number is correct! Extensive off-line data validation procedures were therefore required to examine the data after the fact. This proved to be very time consuming and highly inefficient. It became obvious that implementing data integrity checks within the software in order to catch as many potential data problems as possible in real-time would greatly increase SWEPP throughput and efficiency. Unfortunately, Version 1.0 of SAS was almost completed before all of the problems in the historical data had been discovered.

One thing that stood out from examination of the historical data: There were many examples of the neutron counters within the door of the assay chamber malfunctioning; they would be intermittent over a period of several days and then cease to function entirely. This apparently resulted from flexing of the signal cables from the detector assemblies. (See Reference 6 for a description of the PAN counting chamber and detector assemblies.) An "eleventh hour" modifi-
cation was made to Version 1.0 of the software to check for consistency between count-rates observed from the detectors in the four sides of the assay chamber. Count-rates from the counters in the top and bottom of the chamber were not included because these rates vary relative to rates from counters in the sides from waste drum to waste drum. A note was added to the data display window indicating the amount of variation. Unfortunately, this note usually went unobserved by the PAN operators. In SAS Version 2.0, the side-counter consistency checks were expanded to take into account variations due to counting statistics and a prominent warning window is displayed, shown in Figure 1, when the variation exceeded what would be expected at the 99% confidence level. Data from the offending counters are also highlighted in the data display window as shown in Figure 2.

Figure 1. Warning message indicating a disparity between count-rates from detector banks around the sides of the assay chamber.

Figure 2. Questionable data are highlighted for ease of recognition.
Additional data integrity tests were added in Version 2.0. These include:

- Check for no counts from individual detector banks during a passive assay.
- Check for passive coincidence rates statistically less than zero (at a 95% confidence level).
- Check for unusually low flux monitor counts during active neutron interrogation indicating possible neutron generator malfunction or extremely high neutron absorption in the waste matrix.a
- Check background coincidence rates (passive) against "nominal" background rates read from a configuration file.

If any data integrity test fails, a prominent message is displayed on the screen and an acknowledgment is required from the operator in order to proceed. Serious problems such as no counts from one or more detector banks or high passive background rates are noted in a logging file along with the drum (or background) identification number, date, time of day and operator name.

AUTOMATIC HANDLING OF STATISTICAL UNCERTAINTIES

Like most high-level computer languages, the C++ language (in which SAS is written) has provisions for "user defined" data types. Somewhat unique, however, is the ability to also redefine how operations such as addition, subtraction, multiplication etc. are applied to specific data types. This capability is called "operator overloading". These capabilities of the C++ language – user defined data types (or "objects") and operator overloading – were put to good use in the original SAS development by defining a special data type to represent a measured value (e.g., detector count or count-rate) and its one standard deviation uncertainty. This data type was named "error_bar". Common arithmetic operations on error_bar data objects were "overloaded" to automatically perform error propagation. For example, if $A$ and $B$ are two error_bar objects,

\[ A \pm \sigma_A \quad \text{and} \quad B \pm \sigma_B \]

a. Minimum acceptable flux monitor counts per 2000 neutron pulses are read from a configuration file.
then the result of adding $A$ and $B$ will be an error_bar object containing the sum of the "value" components of $A$ and $B$ and the uncertainties of $A$ and $B$ added in quadrature. Similar results are produced when error_bar objects are subtracted from, multiplied or divided by, or set equal to other error_bar objects or "normal" (floating point) numbers; the error propagation is taken care of automatically without the programmer having to explicitly code the error propagation equation for each operation. This is not only a tremendous time saver when error_bar objects are present in complex equations, but also eliminates a source of potential coding errors.

In SAS Version 2.0, operator overloading was expanded to include standard comparison operations (greater than, less than, greater than or equal to, etc.) involving error_bar objects. By default, the comparisons are performed using 95% confidence level statistics (the standard deviations are multiplied by 1.960). A different confidence level can be set via a “member function” for any error_bar object. The following code segment illustrates how the “equal to” operator is implemented for comparisons between two error_bar objects:

```c
int error_bar::operator == ( const error_bar &eb )
{
    return (float)fabs( datum - eb.d_datum ) -
            CF * (float)sqrt( pow(error, 2) +
                               pow(eb.error, 2) ) <= 0.0;
}
```

In the above, “datum” refers to the value part of an error_bar object and “error” refers to the one standard deviation of the value. “CF” is the confidence factor, 1.960 by default.

**INTEGRATION WITH SWEPP GAMMA-RAY SPECTROSCOPY SYSTEM**

The SWEPP Gamma-Ray Spectroscopy System (SGRS) was just being brought on-line when the new PAN software was installed. This system is used to determine the relative abundance of selected nuclides within a waste drum. These relative abundances are reported as isotopic mass ratios. In the case of plutonium isotopes, the ratios are with respect to $^{239}$Pu; $^{241}$Am is also reported relative to $^{239}$Pu. A data link was setup between the VAX computer controlling the SGRS and the PC controlling the PAN system using DECnet®. This link allows a disk directory on the VAX to appear to the PC as a local disk. The SGRS stores mass ratio results in files that can be accessed directly by the PAN PC. It was initially assumed that the SGRS generated mass
ratios could be used directly to correct for isotopic abundance variations in the plutonium and to determine the $^{241}\text{Am}$ content of waste drums. However, several problems were encountered:

- The SGRS was often unable to obtain a reliable value for the $^{240}\text{Pu}/^{239}\text{Pu}$ mass ratio – a fundamental quantity required to interpret PAN passive assay results.
- Many process sludge waste drums contained significant $^{241}\text{Am}$ but very little plutonium, making it difficult to obtain reliable $^{241}\text{Am}/^{239}\text{Pu}$ mass ratio values.
- SGRS measurements indicated that many waste drums contained enough depleted uranium to interfere with PAN active assay measurements of $^{239}\text{Pu}$ (due to the presence of $^{235}\text{U}$).

The presence of large (multiple kilogram) quantities of depleted uranium in the TRU waste was entirely unexpected. The presence of gram quantities of $^{235}\text{U}$ (present in the depleted uranium) and higher than expected $^{241}\text{Am}$ content caused a break-down in the algorithms used in the SGRS to determine plutonium mass ratios. In addition, $^{235}\text{U}$ was being falsely reported as $^{239}\text{Pu}$ by PAN system assays based on active neutron interrogation. The SGRS algorithms were modified to accommodate high $^{241}\text{Am}$ concentrations and the presence of $^{235}\text{U}$. The SGRS software was also modified to report $^{235}\text{U}/^{239}\text{Pu}$ and $^{241}\text{Am}/^{235}\text{U}$ mass ratios when detectable quantities of $^{235}\text{U}$ were present. It soon became apparent that the SAS software required some major modifications in order to make more intelligent use of the mass ratio values generated by the SGRS.

The following changes were incorporated in SAS Version 2.0 to better utilize SGRS mass ratio results:

- SGRS $^{235}\text{U}/^{239}\text{Pu}$ values used to correct plutonium active assay results and calculate $^{235}\text{U}$ mass (included in output report and activity, etc. calculations).
- SGRS $^{241}\text{Am}/^{235}\text{U}$ values used to calculate $^{241}\text{Am}$ content when $^{241}\text{Am}/^{239}\text{Pu}$ value could not be determined or the ratio relative to $^{235}\text{U}$ has lower uncertainty.
- SGRS plutonium mass ratios used only to confirm that the plutonium isotopic composition is as expected for the waste stream.\(^a\)

The new SAS software version currently nearing completion will report \(^{238}\text{U}\) isotopic mass computed from the \(^{235}\text{U}/^{238}\text{U}\) mass ratio that will be reported by a new version of the SGRS software. It will also treat \(^{235}\text{U}\) as being the primary fissile isotope when SGRS results indicate that considerably more \(^{235}\text{U}\) is present than \(^{239}\text{Pu}\). \(^{239}\text{Pu}\) is currently assumed to be the primary fissile isotope and active assay results are corrected for any \(^{235}\text{U}\) present; this results in large corrections and hence very large uncertainties when the fissile content is primarily \(^{235}\text{U}\). SAS computes the final assay results based on PAN and SGRS measurements and displays them on-screen (Figure 3), prints a “short form” report, saves raw counting data along with intermediate calculation results and the final assay results in a “long form” data file and, when operated in “Remote” mode, automatically uploads the assay results to a SWEPP database management system.

![Figure 3. Integrated PAN/SGRS Measurement Results Window.](image)

\(^a\) Configuration file parameters control how SGRS plutonium isotopic information will be used. The available options are: 1) Always use SGRS isotopic ratios to determine plutonium isotopic masses; 2) Use SGRS isotopic ratios to determine plutonium isotopic masses only if mass ratios are not within normal range; 3) Always use default plutonium mass ratios but indicate to the operator and on the output report when SGRS values are not within expected range; 4) Ignore SGRS results and use default plutonium mass ratios. The third option is the one currently in use at SWEPP.
SHIFT REGISTER COINCIDENCE ANALYZER SUPPORT

Many of the waste drums located at SWEPP contain significant amounts of $^{241}\text{Am}$ and chemical elements (F, B, etc.) that have high $(\alpha, n)$ neutron yields. The resulting high uncorrelated neutron flux from these drums severely interferes with passive neutron assay measurements performed by the PAN system resulting in large measurement uncertainties. This situation can be improved by using a neutron coincidence technique based on “shift-registers” rather than the standard PAN coincidence technique that uses standard delayed coincidence logic. The standard PAN coincidence system “saturates” at high count rates and only information from a set of “shielded” detectors can be used resulting in a loss of counting efficiency and accuracy. A shift-register coincidence system has much lower dead time losses and events from all detectors can be used at high counting rates resulting in much less measurement uncertainty.

A model JSR-12 Neutron Coincidence Analyzer which uses shift-register coincidence technology is scheduled to be installed in the PAN system early in 1997. The JSR-12 has an RS-232 interface that allows complete data acquisition control, parameter and data transfers to be performed by an external device. The new version of the SAS software scheduled for installation at the same time includes the necessary modifications to communicate with the JSR-12. The new software can use either the JSR-12 or the standard PAN coincidence unit (using standard CAMAC modules) for data acquisition. “Long form” data files that do not contain shift register data can still be read and reanalyzed with new matrix or calibration parameters for complete backward compatibility.

Data integrity checks specific to the JSR-12 have also been implemented. For example, the JSR-12 directly measures the accidental coincidence rate and this measured rate is compared with the expected accidental coincidence rate based on the total count rate and the shift register

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a. Manufactured by Canberra Industries, Inc., Meridian, CT.
gate width. A significant lack of agreement\textsuperscript{a} between these two rates indicates a possible hardware malfunction or incorrect parameter setting.

On-line diagnostics can be used to exercise and verify parameter uploading, data acquisition and control functions via the JSR-12 / computer interface. These diagnostics are intended to be performed with a neutron source in the assay chamber so that agreement between measured and calculated accidental coincidence rates can be verified. Diagnostic results are displayed as shown in Figure 4. Hardware diagnostics are accessible only to users with “Physicist” access privilege\textsuperscript{b} and are not part of normal assay procedures.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{shift_register_diagnostics_window.png}
\caption{Shift register diagnostics window.}
\end{figure}

\section*{ACKNOWLEDGMENTS}

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\textsuperscript{a} This comparison is made at a 99.9\% confidence level to reduce the chance of falsely indicating a failure. However, the test is still sensitive enough to catch most real failures.

\textsuperscript{b} The SAS software requires user log-in and recognizes three access levels: “Administrator”, “Operator” and “Physicist”. An “Administrator” can set/reset user passwords and print log and error files. An “Operator” can perform normal assay operations. A “Physicist” can access matrix, calibration and configuration parameters, perform hardware diagnostics, and perform “Operator” functions.
vided by G. W. Twedell. Operational requirements and technical oversight for the initial SAS development were provided by G. K. Becker.

REFERENCES


