2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-03-8**

DEVELOPMENT OF THE SOFTWARE DEAD TIME METHODOLOGY FOR THE 4πβ-γ SOFTWARE COINCIDENCE SYSTEM ANALYSIS PROGRAM

Fábio de Toledo, Franco Brancaccio and Mauro da Silva Dias

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN – SP)
Av. Professor Lineu Prestes, 2242
05508-000 São Paulo, SP
fatoledo@ipen.br
fbrancac@ipen.br
msdias@ipen.br

ABSTRACT

The Laboratório de Metrologia Nuclear – LMN, Nuclear Metrology Laboratory –, at IPEN-CNEN/SP, São Paulo, Brazil, developed a new Software Coincidence System (SCS) for 4πβ-γ radioisotope standardization. SCS is composed by the data acquisition hardware, for the coincidence data recording, and the coincidence data analysis program that performs the radioactive activity calculation for the target sample. Due to hardware intrinsic signal sampling characteristics, multiple undesired data recording occurs from a single saturated pulse. Also pulse pileup leads to bad data recording. As the beta counting rates are much greater than the gamma ones, due to the high 4π geometry beta detecting efficiencies, the beta counting significantly increases because of multiple pulse recordings, resulting in a respective increasing in the calculated activity value. In order to minimize such bad recordings effect, a *software dead time* value was introduced in the coincidence analysis program, under development at LMN, discarding multiple recordings, due to pulse pileup or saturation. This work presents the methodology developed to determine the optimal *software dead time* data value, for better accuracy results attaining, and discusses the results, pointing to software improvement possibilities.

1. INTRODUCTION

In the Nuclear Metrology field, the 4πβ-γ coincidence method for radionuclide activity measurement is considered as a primary standard, because of its dependence of a few observable quantities in order to attain high accuracy results [1-10].

The Software Coincidence System (SCS) is the new contribution for the LMN radioisotope standardization systems. SCS operates connected to any nuclear detection arrangement. For this work, the detection arrangement of the conventional coincidence system was employed – a proportional detector in 4π geometry (for beta detection), coupled to a NaI(Tl) scintillation crystal (for gamma detection). SCS hardware is composed by a National Instruments (NI) data acquisition card, coupled to a microcomputer and managed by software, developed with the NI LabVIEW graphical programming tool. The hardware performs the disk files recording of the amplitudes and occurrence instants of all the detected beta and gamma pulses from the nuclear 4πβ-γ detection arrangement. In a second step, the saved data files are processed by the coincidence analysis program, under development at LMN [11], in order to obtain the beta, gamma and coincidence counts, and then, calculate the activity of the target radionuclide. This software process includes compensation corrections for the background radiation (BG), for the radioactive decay and for the system dead times. BG and decay corrections are trivial. But, dead time corrections require the previous knowledge of the accurate system dead times.

At a first instance, a set of measurements for the SCS dead time values determination was performed. However, the first experimental activity obtained values were about 1% greater than those obtained with the conventional systems. Some unexpected effect was occurring, acting in a counter way, and, instead of the waited activity value losses due to dead times, increased values were obtained. The fact pointed to the need of an investigation of the probable causes of such undesired effects, which origin should be both in the data recording or analyzing. The scope of this work is to present the methodology developed for the problem seeking, identification and minimization. Results and conclusion are also presented.

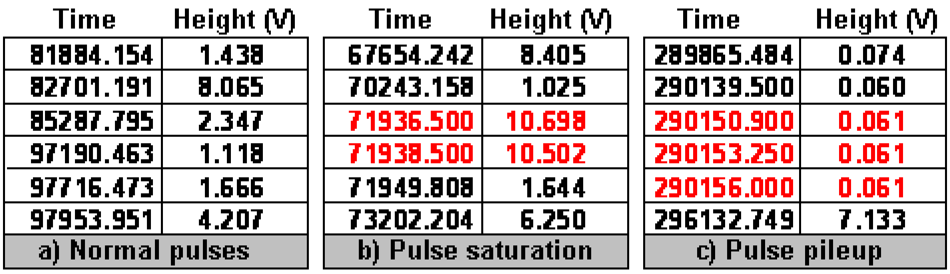
2. SOFTWARE DEAD TIME DETERMINATION METHODOLOGY

The activity value increasing pointed above, may result from coincidence count losses or from event counting rates super estimation. In any case, the real cause must be identified in order to find the proper correction.

2.1. SCS Data Files Analysis

Prior to look for an imprecision in the coincidence analysis program code, an analysis of the data files contents was realized. Fortunately, a close overview in the ASCII data soon revealed important facts: some pulse data records have very close time and amplitude values, and, in many of them the amplitude voltages match the amplifying modules saturation values (~10V), mainly for the beta data files, where the counting rate is much greater because of the high beta detector efficiency (proportional counter in 4π geometry). A simple counting from software obtained spectra showed that almost 6% of the total beta pulses are saturated, against almost 2% of the total gamma pulses. To avoid significant losses in the beta counting, the saturated pulses are also computed for activity calculation. But in SCS such a pulse may originate more than one data record and, instead of count losses, false increased counts are obtained. Saturation is not a problem for the gamma pulses, since only the amplitudes remaining into the total absorption peaks are computed. Tab. 1 presents three fragments of ^{60}Co standardization beta data file. Data highlighted lines show two types of undesired information recording, as explained below.

Table 1. Three fragments of ^{60}Co beta data file showing normal and undesired data recording.



Time	Height (V)	Time	Height (V)	Time	Height (V)
81884.154	1.438	67654.242	8.405	289865.484	0.074
82701.191	8.065	70243.158	1.025	290139.500	0.060
85287.795	2.347	71936.500	10.698	290150.900	0.061
97190.463	1.118	71938.500	10.502	290153.250	0.061
97716.473	1.666	71949.808	1.644	290156.000	0.061
97953.951	4.207	73202.204	6.250	296132.749	7.133
a) Normal pulses		b) Pulse saturation		c) Pulse pileup	

The first columns of each block in Tab. 1 contain the pulse-time information as a multiple of PCI6132 signal sampling period (400ns). Decimal time information is obtained by the Peak Detector (LabVIEW PD-VI tool), after the signal reconstitution (internal PD-VI software feature). Pulse amplitudes (Volts) are given in the second columns. Tab. 1-a shows a normal data recording of time distant pulses. The minimum observed time is very large, about 90 µs. In Tab. 1-b, the two highlighted records correspond to a single saturated pulse. The voltage saturation value could be noticed, as well as the time difference between records, exactly matching the hardware sampling period. Tab. 1-c, at last, shows the evidence of pulse pileup. The nuclear detecting electronics have characteristic times for the pulse formation and, thus, two or more very narrow pulses could not be distinguished, resulting in a larger width pileup pulse. Both cases showed in Tab. 1-b and Tab. 1-c result in bad information recording that need to be corrected or compensated. Software correction was considered the best option, easier than hardware reconfiguring or than making changes in the LabVIEW acquisition managing software.

Fig. 1 shows the beta and gamma pulse height count histograms from a SCS standardization of ^{60}Co source. Graphs were edited, including yellow highlighting of the saturation areas, for beta and gamma pulses, around 6% and 2%, respectively, of the total observed pulses.

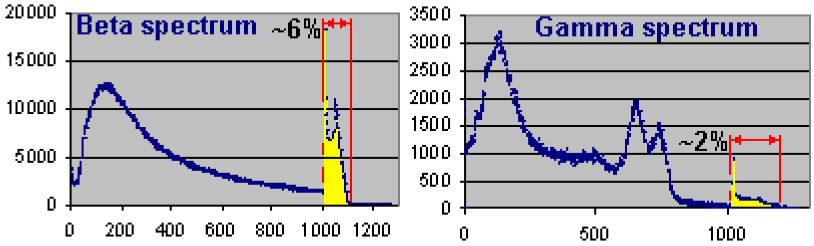


Figure 1. Beta and gamma spectra obtained from a SCS standardization of ^{60}Co sample, edited to highlight the saturation voltages respective areas.

2. 2. Beta Detection Pulse Signal Analysis

For more accurate understanding of the presented facts, the beta pulse output signal was registered and analyzed (the beta channel spectroscopy amplifier output signal), by using ^{60}Co source and a digital oscilloscope. Figures 2 and 3 present fragments of the oscilloscope screen snapshots. Again, some figure edition was introduced, for voltage levels emphasizing, as well as timing and signal digitalization detailing. In Fig. 2-a, all the pulses have good shaping. The pulse separation times are large enough for the proper pulse formation at the electronic stages. Fig. 2-b shows two pulses separated by about 1.5 µs, presenting a partial pulse pileup (superposition). In this particular case, nevertheless the partial superposition, both pulses have well defined peaks and the data recording is perfectly accomplished. Fig. 3 presents pileup resulting pulses and a pulse saturation case.

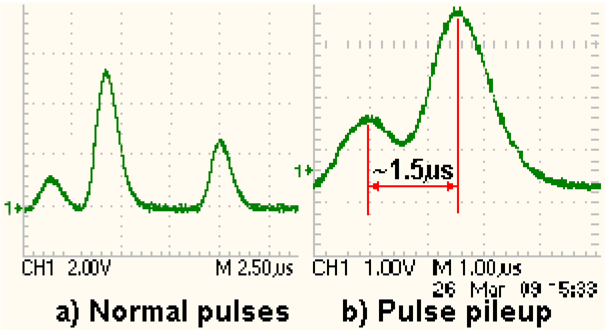


Figure 2. Signal from the beta channel spectroscopy amplifier output with well defined peaks.

Fig. 3-a and Fig. 3-b shows two pileup cases, respectively, two pulses with close amplitudes and three pulses with well differentiated amplitudes. In both cases the pulse time distances are about 1 µs and the resultant pileup pulses have enlarged widths. Red dots were added as a representation of each pileup-enclosed pulse. In Fig. 3-c, the added blue vertical lines represent, approximately in scale, the SCS sampling instants. Over the flat peak saturation region, three points of maximum can be seen, resulting in three data records. Actually, two or three records are observed in the data files for a single saturated pulse.

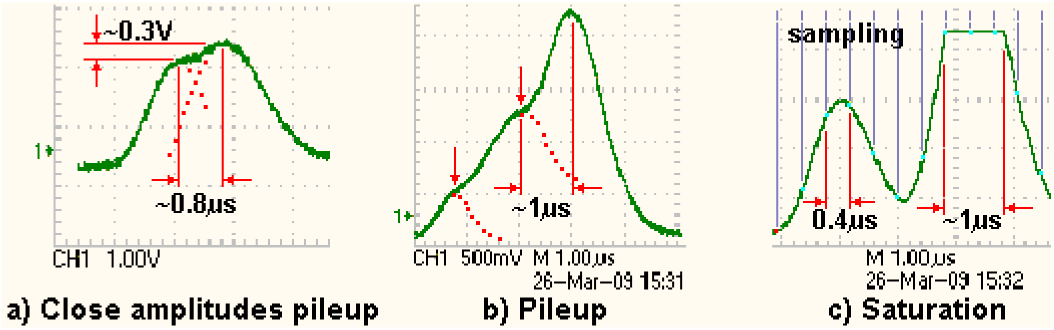


Figure 3. Signal from the beta channel spectroscopy amplifier output with peak degradations (pileup and saturation).

2.3. SCS Software Dead Time (SDT)

The SCS dead times determination, by conventional techniques, is a difficult task because of the hardware characteristics. Some auxiliary electronic modules should be necessary and additional sources of dead times should be introduced.

Software was the elected tool in order to minimize the above pointed effects. The undesired data files records should be, anyway, discarded by the analysis software, by introducing a *software dead time* (SDT). After one record reading, the subsequent records that remain inside the SDT range could be rejected, do not contributing to respective pulse count neither to the coincidence analysis computation. It is a simple task, however an optimal SDT range should be defined, and the probable resulting losses compensated.

Due to the system signal digitalization features, it can be considered that all the significant signal information is saved onto the files and SCS dead times are virtually zero. However, losses occur due to pulse pileup, and multiple recording of a single saturated pulse also occur. From figures 2 and 3 it can be deduced that pulses are well resolved for pulse time separations greater than 1.5 μs and significant pileup occurs for times ranging about 1.0 μs. Also, the flat saturation peak width is about 1.0 μs, suggesting that the optimal SDT value remains into the 1.0-1.5 μs range.

2.4. Activity Calculation for SDT Optimization

SDT was introduced in the analysis software code, allowing the attaining of two sets of activity values from the same ^{60}Co data files, for different SDT values, ranging from 0 to 30 μs. Each SDT value was treated as the actual SCS dead times, for both beta and gamma channels, in the first set of activity values attaining, taking the conventional dead time compensation [12] into account. The second set skips the dead time corrections. Since the SCS obtained activity values are about 1% greater than those obtained with the conventional systems, the searching for the ideal SDT value corresponds to the searching for such difference minimization. The results of the two analyzing sets are given by the graphs in Fig. 4-a and Fig. 4-b, showing the activity values as function of the SDT ranges, respectively, with and without dead times corrections.

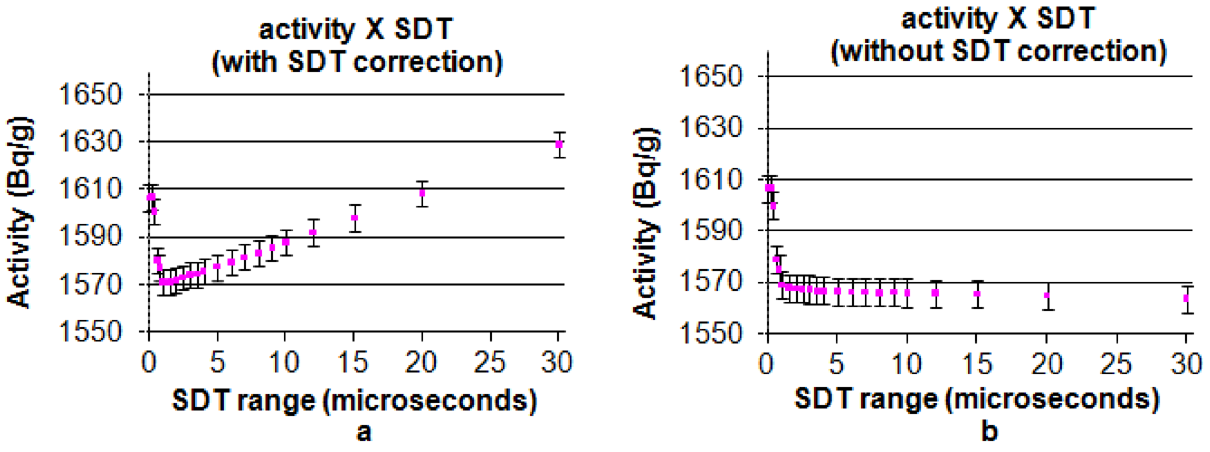


Figure 4. Activity values obtained by SDT computation, with corrections (case a) and without corrections (case b).

In both cases, the activity values abruptly decrease in the 0 to 1.5 μs SDT range. In the first case, a point of minimum is observed. To SDT values above 1.5 μs, the activity values again increase, probably because dead time corrections are overestimated in such a case. SDT, maybe, is quite different of actual system dead times and the conventional correction formality cannot be appropriately applied. The dead time corrections were suppressed in the second set of measurements, and curve behavior is quite different, for SDTs greater than 1.5 μs, with slight decreasing activity values.

Fig. 4 suggests that conventional dead time corrections (case a) are, in fact, overestimated for this particular case. The regions above 1.5 μs in both cases have good linearity and were selected for the data fitting showed in Fig. 5.

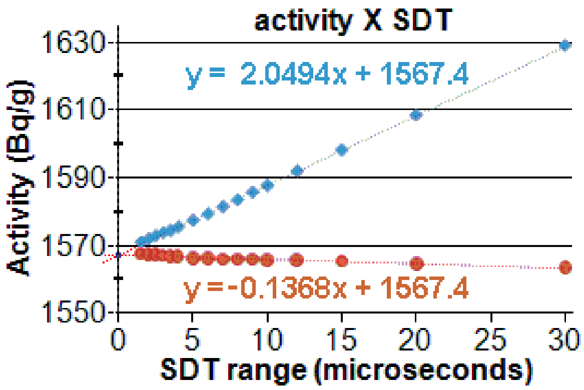


Figure 5. Linear fitting of activity values for SDT ranging from 1.5 μs to 30 μs, for both cases of Fig.5.

Fig. 6 shows the plots for the beta, gamma and coincidence counts obtained on the process, for each SDT range value.

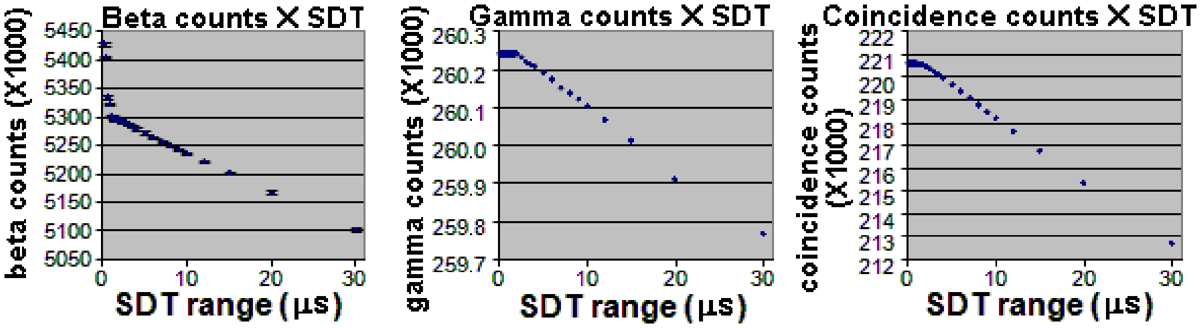


Figure 6. Beta, gamma and coincidence counts versus SDT range values.

The beta counts behavior, for low SDTs, clearly explains the activity behavior in the same region (Fig. 4). As the time range for subsequent pulses rejection (SDT) increases, the multiple beta records begin to be discarded, leading to the linear region. The coincidence counts follow the gamma counts and behaviors are similar. More probably, two subsequent gamma pulses are distant in time, and low SDTs actually do not affect the gamma counts. For greater SDT range values the gamma counts begin to decrease. The three curves have an inflexion point for SDT valuing about 1.5 μs that matches the anticipated value in the item 2.3 (the chosen minimum SDT for the curve fitting in Fig. 5).

Fig. 5 includes the fitted lines equations. The two intercept values match, corresponding to the extrapolated activities for a null SDT, here assumed as the optimized activity value of the ^{60}Co target sample: 1567.4 ± 5.3 Bq/g.

Table 2 shows the obtained activity values for the same ^{60}Co sample standardizations, from conventional coincidence system (the reference system) and from SCS (the target system). Two SCS results were obtained from a same data file set. The second SCS value calculation includes SDT corrections and the result is better than the previous one (without SDT corrections). Inside the uncertainty margin, the corrected value is more consistent. The difference to the reference value was reduced, approximately, from 1% to 0.4%.

Table 2. The ^{60}Co sample obtained activity values

Standardization system	**Activity (Bq/g)**	**Uncertainty (Bq/g)**	**Difference (%)**
Conventional System (Reference)	**1561.1**	**2.4**	**0.0**
SCS (before SDT methodology)	1578.0	5.4	1.1
SCS (SDT methodology)	1567.4	5.3	0.4

3. CONCLUSIONS

The concept of software dead time (SDT) has been introduced in the Software Coincidence System (SCS). Experimentation and analysis guided to the new methodology development, in order to minimize the effects of data losses in the nuclear detecting systems and of undesired multiple data recording, caused by SCS signal digitalizing intrinsic features. Basically, the method consists in the insertion of artificial *software dead times*, in order to obtain the activity values as a function of SDT ranges; the two extremes of significant undesired effects are then discarded; thus, from the linear fitting (Fig. 5), the activity is determined as the extrapolated value for a null SDT range. The activity value from SCS standardization of ^{60}Co including SDT corrections is consistent to that obtained from conventional coincidence system and the difference was reduced from ~1% to. ~0.4%. However, the validation of the presented methodology depends on the realization of many SCS standardizations, for different radionuclide samples. There is a great potential for the method improvement and many features can be added. The development of SCS will lead to the introduction of improved methods, allowing new areas to be investigated.

ACKNOWLEDGMENTS

The authors would like to make a special mention to Dr. Guilherme Soares Zahn, for the inestimable help and significant suggestions.

REFERENCES

1. CAMPION, P. J., The standardization of radioisotopes by beta-gamma coincidence method using high efficiency detectors. *Int. J. Appl. Radiat. Iso.*, 4, p: 232-248, 1959.
2. GANDY, A., Mesure absolute de l'activité des radionucléides par la méthode des coincidences beta-gamma à l'aide de détecteurs de grand efficacité - Étude des coincidences instrumentales. *Int. Journ. Appl. Radiat. Isot.* 11, p: 75, 1961.
3. GANDY, A., Mesure absolute de l'activité des radionucléides par la méthode des coincidences beta-gamma à l'aide de détecteurs de grand efficacité - Corretions de temps morts. *Int. Journ. Appi. Radiat. Isot.* 13, p: 501, 1962.
4. BAERG, A. P., Measurement of radioactivity disintegration rate by the coincidence method. *Metrologia*, 2 (1), p: 23-32, 1966 .
5. BAERG, A. P., Absolute measurement of radioactivity. *Metrologia*, 3 (4), p: 105-108, 1967.
6. BAERG, A. P., The efficiency extrapolation method in coincidence counting. *Nuclear Instruments and Methods*. 112, p: 143-150, 1973.
7. HOUTHERMANS, H., MIGUEL, M. $4\pi\beta$-γ coincidence counting for the calibration of nuclides with complex decay schemes. *Int. J. Appl. Radiat. Isot.* 13 p:137-142 , 1962.
8. KAWADA, Y., Extended applications and improvement of the $4\pi\beta$-γ coincidence method in the standardization of radionuclides. *Res. of ETL*. Japan, ETL-730, 1972.
9. TAYLOR, J. G. V., The total internal conversion coefficient of the 279 keV transition following the decay of ^{203}Hg as measured by a new coincidence method. *Canad. Journ. Phys.*, 40 (4) p: 383, 1962.
10. MOURA, L. P., Método de Coincidência Generalizado para a Medida Absoluta da Atividade de Radionuclídeos - Aplicação da Determinação do Coeficiente de Conversão Interna da Transição de 279 keV do ^{203}Tl. *Tese de Doutorado apresentada à Universidade de Campinas*, 1969.
11. Brancaccio, F.; Dias, M. S.; Toledo, F., "Development of an Analysis Methodology Applied to $4\pi\beta-\gamma$ Software Coincidence Data Acquisition System", submitted to the *International Nuclear Atlantic Conference - INAC 2009*, Rio de Janeiro, RJ, Brazil, September 27 to October 2 (2009).
12. SIMÕES, D. Padronização dos Radionuclídeos Multi-Emissores Gama ^{66m}Ho e ^{72}Ga e determinação de suas intensidades gama por decaimento., *Tese de Doutorado apresentada ao Instituto de Pesquisas Energéticas e Nucleares/USP* (2005).