

CHAPTER 29

Efficiency Extrapolation Adapted to Liquid Scintillation Counters

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ABSTRACT

Efficiency extrapolation applied to β emitters has been adapted previously to conventional liquid scintillation counters. This concept has been extended to cover broad quench ranges, it has also been extended to cover tritium with a small decrease in accuracy compared with *a priori* approaches.

INTRODUCTION

The disintegration rate of an unknown β -emitting nuclide may be obtained by using a standard β -emitting nuclide to determine the overall system efficiency of a counter. Initial work by Gibson and Gale^{1,2} was followed by Malonda and colleagues,³⁻⁵ and used by Coursey et al.⁶ who reviewed it, as did NCRP Report Number 58.⁷

This approach computes the detector efficiency for a two-phototube coincident counting system. An efficiency curve of a standard is measured experimentally in terms of a selected quench parameter (Q). That permits calculation of the corresponding figure of merit (M) of the system via the Fermi β -ray spectral distribution for the standard. The distribution is corrected for two energy exchange processes that do not contribute to photon production: ionization quenching and the wall effect. These corrections provide a figure of merit independent of the detectable energy of the counting system. Therefore the figure of merit can be expressed as a function of the selected quench parameter:

$$M = f(Q) \quad (1)$$

With that independence, the efficiency, $\epsilon(\text{unk})$, of an unknown beta emitter can be computed from the Fermi spectral distribution corrected for ionization quenching and the wall effect:

Table 1. Summary of Variables Studied

Isotopes: ^3H , ^{63}Ni , ^{14}C , ^{35}S , ^{22}Na , ^{36}Cl , ^{32}P , ^{241}Am
Cocktails: Toluene, Xylene and Pseudocumene based gel, Non-emulsifier, Biodegradable
Volume: 0.4–16 ML.
Count rates: 1000–6 Million
Quench range: 0–475 H#
Reference standards: ^3H , ^{14}C
^3H , ^{63}Ni , ^{14}C , ^{36}Cl , and ^{241}Am (NIST - SRMs)
^{35}S , ^{22}Na and ^{32}P Not as well characterized monitored by quench curves

$$\epsilon(\text{unk}) = f(M) \quad (2)$$

From Equations 1 and 2,

$$\epsilon(\text{unk}) = f(Q) \quad (3)$$

is available. The quench curve of the unknown has been calculated from the experimentally measured quench curve of the standard. Details of this approach are available in References 3 through 7 and their bibliographies.

An experimental approach initiated by Ishikawa and colleagues⁸⁻¹⁰ calibrates the counting system efficiency by determining the efficiencies of a standard for six defined pulse height regions. The count rates of an unknown are obtained for the same spectral regions as the standard. This provides integrated (or cumulatively summed) count rates of the unknown as a function of the system integrated efficiency determined by the standard. The resulting linear or quadratic functionality may be extrapolated to 100% efficiency to provide disintegrations of the unknown. Good results have been obtained for reasonable quench ranges.

EXTENDING THE QUENCH RANGE

First examine the use of the complete spectrum of the standard for system calibration and the complete spectra of unknown nuclides for count rate integration. Figure 1 illustrates one result based upon ^{14}C as the standard and quenched samples of ^{35}S as the unknowns. The counting efficiency range of the four ^{35}S samples taken from the same quench set is 60 to 95%. Figure 2 provides analogous data for ^{32}P and ^{36}Cl . Depending upon the quench level of the sample, the specific nuclide, and the resolution of the multichannel analyzer (MCA), tens to hundreds of channel data are available. A 4096 channel MCA provides about 300 channels for an unquenched ^{14}C spectrum.

Several hundred samples have been monitored. The variables examined (nuclides, cocktails, sample volume, count rates, quench levels, and quenching agents) are summarized in Table 1. Various curve fitting and extrapolation algorithms led to an iterative procedure which produces a least squares linear fit. It is subsequently extrapolated as illustrated in Figure 3. Criteria defining linearity are important but not hypercritical. Results reported here are based

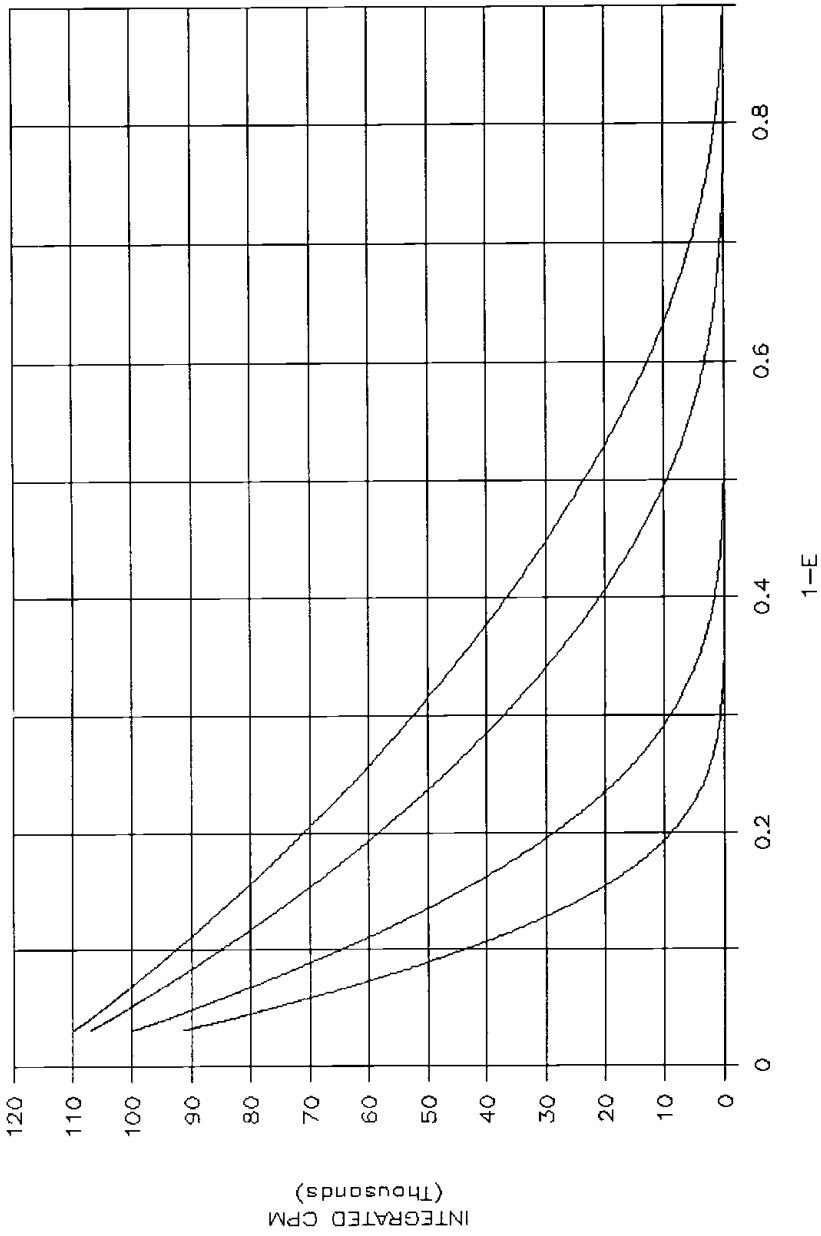


Figure 1. Integrated ^{35}S Spectra vs Integrated Standard ^{14}C Counting Efficiency.

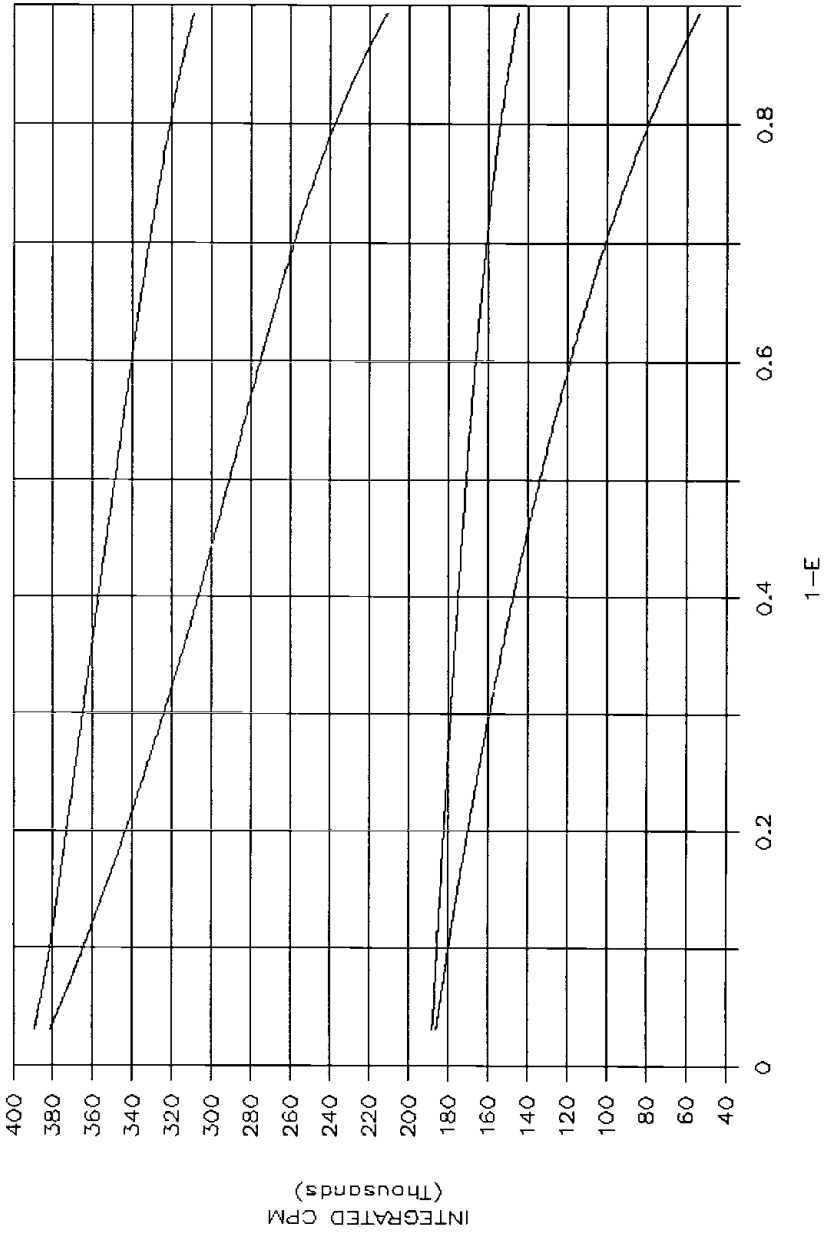


Figure 2. Integrated ³²P and ³⁶Cl Spectra vs Integrated Standard ¹⁴C Counting Efficiency.

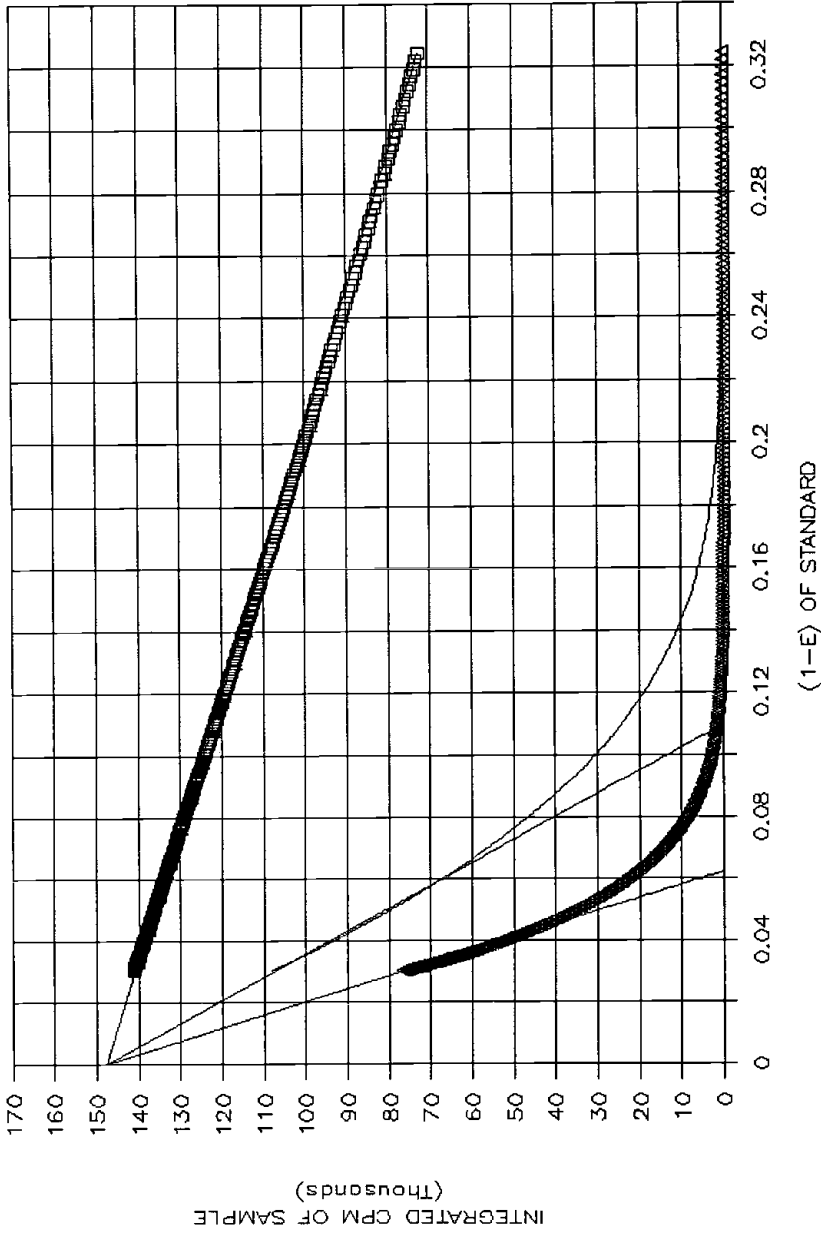


Figure 3. Integrated ^{14}C Spectra vs Integrated Standard ^{14}C Counting Efficiency.

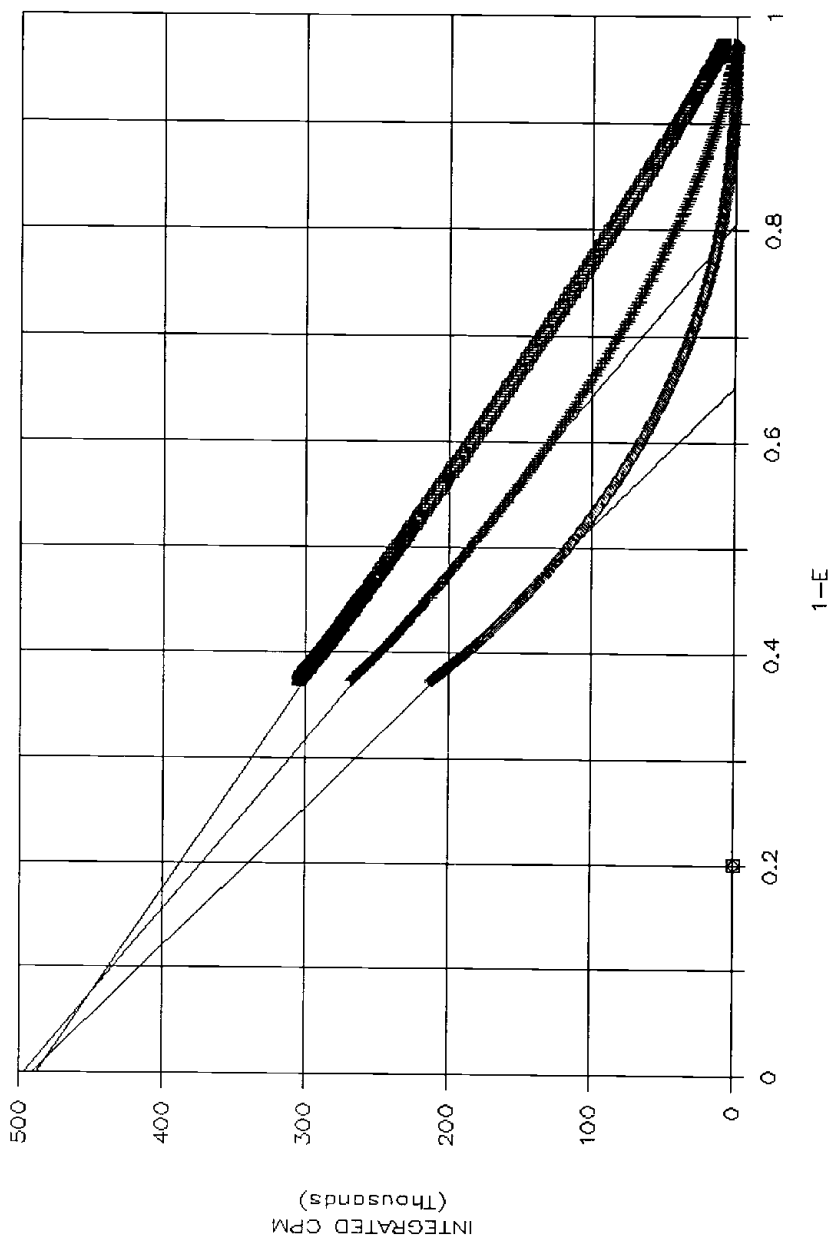


Figure 4. Integrated ^3H Spectra vs Integrated Standard ^3H Counting Efficiency.

Table 2. Results

For H# ranges of 0–350:	0.1 to 3.5% (except H3)
For H# range of 0–150 for H3 (65–30% counting efficiency)	0.1 to 8.1%

upon the square of the correlation coefficient (or coefficient of determination) exceeding 0.99. The three samples shown in Figure 3 were taken from a standard quench set containing 2470 Bq (148000 DPM). The raw data are represented by the thick line, the segment satisfying the linear constraint and subsequent extrapolation is the narrow line. These samples cover a counting efficiency range of 55 to 95% with an error in DPM recovery less than 2%.

APPLICATION TO TRITIUM

Direct application of the procedure to tritium provides useful results if the quench level remains small. For example, % error in DPM recovery for NIST SRMs with counting efficiency above 45% (or Horrocks' numbers less than 75) is less than 4%. However, if tritium unknowns are measured after calibration by tritium standards, recoveries better than 8% are obtained for counting efficiencies of 30%.

A summary of the results is provided by Table 2. The range of the % error in DPM recovery is 0.1 to 3.5% for all nuclides except ^3H for the volume, quench ranges, cocktails, and count rates presented in Table 1. For ^3H monitored for all the same variables but over a quench range of 65 to 30%, the % error range is 0.1 to 8.1%.

Lastly, ongoing work has established that recoveries better than 4% are possible for ^{14}C with efficiencies down to 20% (or Horrocks' numbers of 450) if the system is calibrated by standard ^3H .

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