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SIMULATION OF HLNC AND NCC MEASUREMENTS*

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1. INTRODUCTION

The aim of providing an automatic method of simulating the results of High Level Neutron Coincidence Counting (HLNC) and Neutron Collar Coincidence Counting (NCC) measurements is to facilitate the safeguards' inspectors understanding and use of these instruments under realistic conditions. This would otherwise be expensive, and time-consuming, except at sites designed to handle radioactive materials, and having the necessary variety of fuel elements and other samples. This simulation must thus include the behavior of the instruments for variably constituted and composed fuel elements (including poison rods and Gd loading), and must display the changes in the count rates as a function of these characteristics, as well as of various instrumental parameters. Such a simulation is an efficient way of accomplishing the required familiarization and training of the inspectors by providing a realistic reproduction of the results of such measurements. At present, demonstration of the effects of poisons, impurities, and other sources of uncertainty cannot presently be met in-house in the initial training for advanced courses on the HLNC, UNCL (Uranium Neutron Collar) and AWCC (Active Well Coincidence Counter).

2. CONCEPTUAL SOLUTION

A solution is the development of an IBM-PC compatible software package embodying appropriate algorithms to simulate active-passive neutron coincidence measurements under realistic conditions. Such a program accepts as inputs the mass loading of the sample being measured and its various other relevant characteristics, and

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produces as outputs the count rates that would be observed on an actual neutron coincidence measurement of a sample with the same characteristics. To simulate the effects of uncertainties in the sample characteristics and instrumental parameters, the physical parameters are allowed to vary according to a reasonable statistical distribution, and the calculation is then repeated a number of times to compute average count rates and their uncertainties. The mass of the sample chosen is then calculated from these simulated count rates.

In particular, in the case of the HLNC, a software program was constructed that simulates the response of the HLNC to plutonium samples covering a range of masses, isotopic compositions, configurations, impurity levels, etc. This program not only calculates the response of the instrument (i.e., the count rates) for such samples, but also performs an error analysis by propagating the errors of the measured, instrumental, and parametric variables[1] to yield the uncertainties in the masses. A central point is the derivation of a leakage multiplication-fissile mass correlation (with three parameters) obtained from an analysis of 123 sets of published experimental data. Using this algorithm, the simulated totals (single) and reals (coincidence pair) count rates agreed with the measurement data to within 10%. Uncertainties in the isotopics, as well as the effects of possible impurities --fluorine and moisture--are also included in this algorithm. The algorithm was subsequently successfully tested against additional data obtained from field measurements on more than one hundred different samples. The PC software based on this algorithm has been developed for inspector training and familiarization with such HLNC measurements and their errors.

3. ALGORITHM DESCRIPTION

As indicated earlier, the algorithm involved is a inversion of the basic HLNC analysis described, for example, in References [1] and [2]. The governing equations are as follows:

[1] The parameters that appear in the analytic algorithms used to calculate the mass from the count rates.

(a) If Pu is the total plutonium mass, then

$$m_f = (f_{239} + f_{241})Pu \tag{1}$$

is the amount of fissile plutonium, f_{239} and f_{241} being the (presumed known) isotopic fractions of the fissile isotopes. This fissile mass is an important intermediate physical variable in the modelling since it determines the neutron multiplication in the sample.

(b) An important intermediate quantity is the parameter which accounts for the effect of (α,n) neutrons, due to oxides and various impurities in the sample. If the sample is composed purely of oxides , and the isotopic fractions are known, then a is given by the expression

$$\alpha = \frac{k_1f_{238}+k_2f_{239}+k_3f_{240}+k_4f_{241}+k_5f_{242}+k_6f_{Am241}}{k_7[k_8f_{238}+f_{240}+k_9f_{242}]} \tag{2}$$

where k_i, $i = 1,...12$ (see also below) are empirical physical constants.

(c) The leakage multiplication M is then given by the empirical correlation

$$M = 1 + \frac{m_f}{A + Bm_f - Cm_f^2} \tag{3}$$

discussed in (d) below.

(d) Another intermediate variable r is then calculated from the quadratic expression

$$r = k_{10}(1 + \alpha)\,M^2 + [1 - k_{10}(1 + \alpha)]M \tag{4}$$

(e) The effective Pu_{240} mass, Pu240eff is given by

$$Pu240eff = (k_{11}f_{238}+f_{240}+k_{12}f_{242})\;Pu \tag{5}$$

(f) The multiplication-corrected reals count rate is

$$R_c = aPu240eff \qquad (6)$$

where a is another calibration constant (see Reference [4] for further discussion of these calibration parameters).

(g) The actual real coincidence counting rate is then

$$R = rMR_c \qquad (7)$$

(h) The totals counting rate is then given by the expression

$$T = R\,(1 + \alpha)/\rho_o r \qquad (8)$$

Here ρ_o is another empirical constant closely related to a, see Reference [4]. This completes the simulation.

In analysis it is usual to determine r from the experimental data and the declared isotopics, via equation (3), then derive M from the quadratic expression (4) and finally obtain Pu from equations (8), (7) , (6), and (5) .

4. CORRELATION BETWEEN THE LEAKAGE MULTIPLICATION AND THE FISSILE MASS

Statistical analysis of the published measurements of 123 samples[2] has disclosed an empirical correlation between the leakage multiplication factor M and the fissile mass m_f, viz.

[2] The provenance of 93 of these measurements may be found in Reference 3. A number of items including substantial amounts of HEU, or moisture were excluded from this analysis. These measurements were augmented by an additional 30 sample measurements made available by JRC (ISPRA).

$$M = 1 + \frac{m_f}{A + Bm_f - Cm_f^2} \quad (3)$$

where A, B, and C are positive constants[3]. (The particular form (10) was chosen to ensure that the physical relation M = 1 for $m_f = 0$ was automatically satisfied.) Though it is to be expected that these constants will change when different groups of samples are examined, subsequent investigations using new, independent, experimental data (all comprising plutonium oxide, PuO_2, samples) have also yielded good results in a variety of applications using this same correlation.

Figure 1 shows the correlation between the leakage multiplication M and the fissile mass m_f, while Fig. 2 shows the application to the declared and calculated values of Pueff.

A similar algorithm, suitable for use with the NCC, is currently under development.

REFERENCES

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[2] KRICK,M., "Algorithms and Software for Data Acquisition and Analysis using Thermal Neutron Coincidence Counters within the IAEA's INFSS/NCC System", ISPO No. 256, LA-UR-88-1301, May 1988 (Los Alamos National Laboratory, Los Alamos, New Mexico)

[3] The values obtained for these published, 123 measurements, are A = 1.5261, B = 8.0656, and C = 0.92594, with a coefficient of determination R^2 = 0.967. The coefficients A, B, and C have respective standard errors of 0.202, 0.242, and 0.0474

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[4] LU, M-S., TEICHMANN, T., DE RIDDER, P., DELAGARD, C., "HLNC Calibration and Application to Waste Measurement", 14th Annual ESARDA Meeting, Salamanca, Spain, 5 - 8 May, 1992, ESARDA 25, (1992) 247-250.

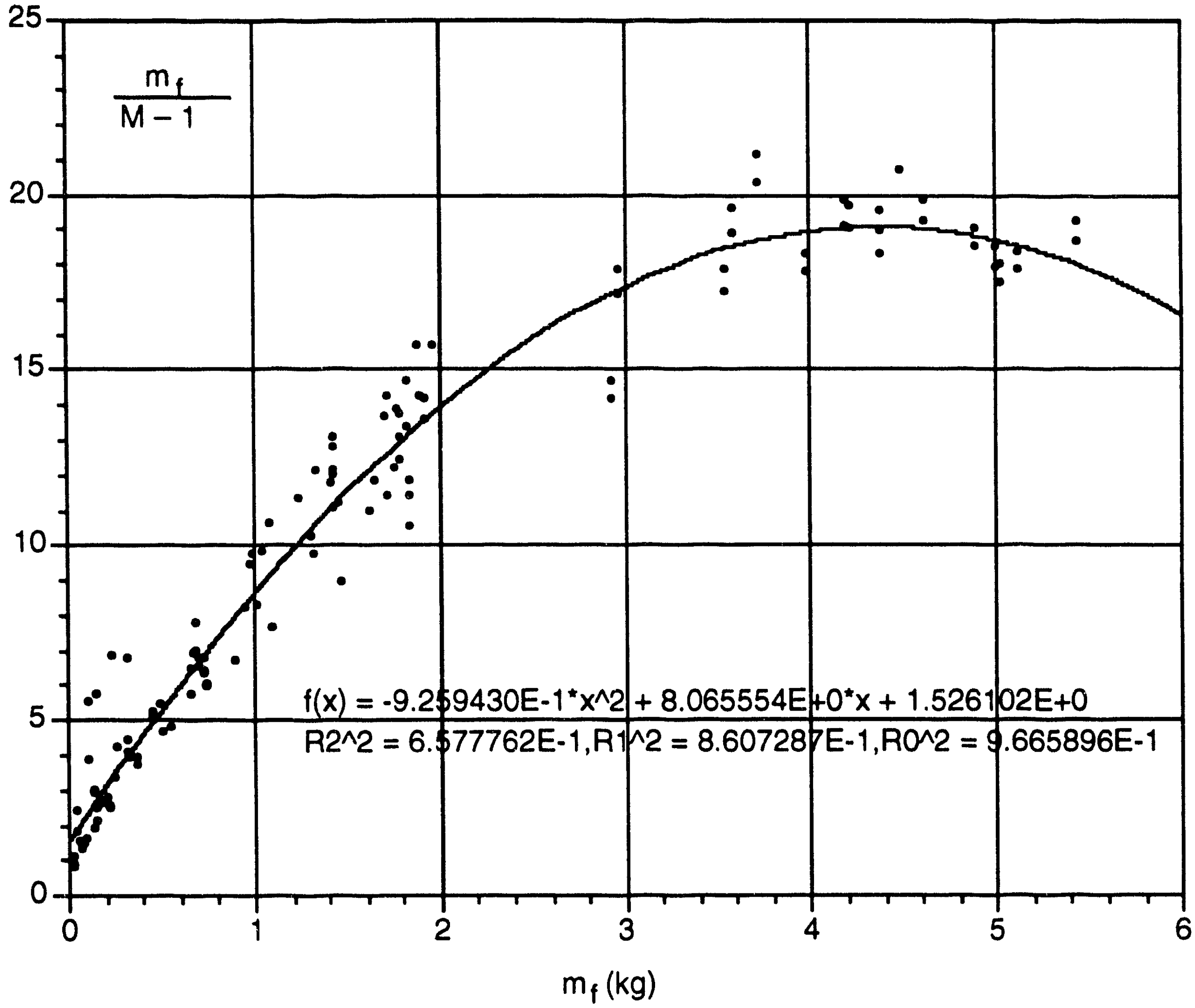

Fig.1: Fissile Mass (m_f)-Multiplication Factor Correlation (123 samples)

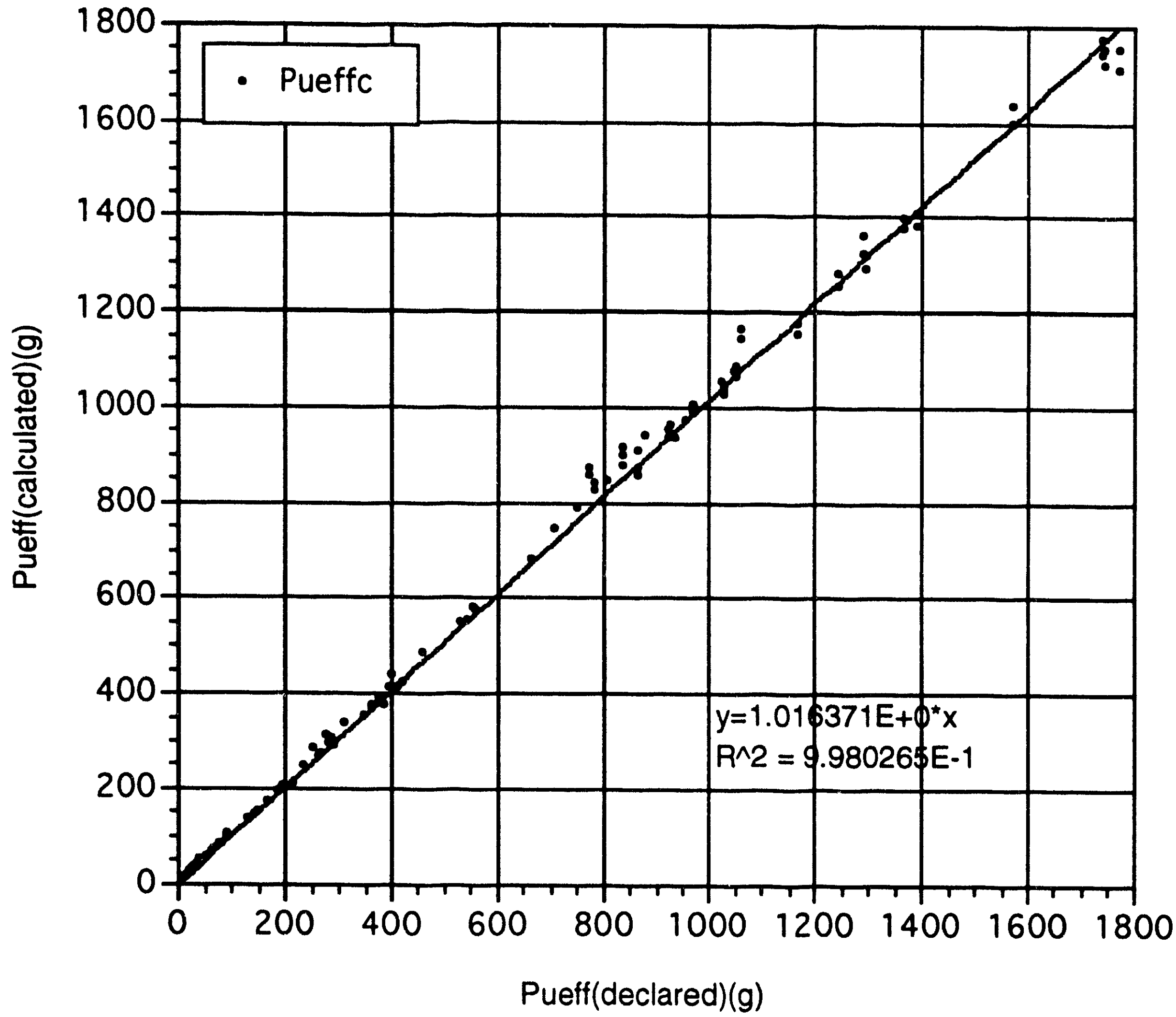

Fig. 2: Comparison of calculated and declared values of Pueff

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