


*FB-Line Neutron Multiplicity Counter
Operation Manual*

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FB-LINE NEUTRON MULTIPLICITY COUNTER OPERATION MANUAL

by

D. G. Langner, M. R. Sweet, S. D. Salazar, K. E. Kroncke

ABSTRACT

This manual describes the design features, performance, and operating characteristics for the FB-Line Neutron Multiplicity Counter (FBLNMC). The FBLNMC counts neutron multiplicities to quantitatively assay plutonium in many forms, including impure scrap and waste. Monte Carlo neutronic calculations were used to design the high-efficiency (57%) detector that has 113 ^3He tubes in a high-density polyethylene body. The new derandomizer circuit is included in the design to reduce deadtime. The FBLNMC can be applied to plutonium masses in the range from a few tens of grams to 5 kg; both conventional coincidence counting and multiplicity counting can be used as appropriate. This manual gives the performance data and preliminary calibration parameters for the FBLNMC.

GENERAL

The FB-Line Neutron Multiplicity Counter (FBLNMC) is a high-efficiency neutron counter designed for measuring the multiplicity of the neutron emissions from both spontaneous fission and induced-fission reactions in plutonium.

The FBLNMC was developed to measure impure plutonium at the Westinghouse Savannah River Site. We performed basic research for the FBLNMC hardware and software under the Department of Energy safeguards research program. The design of the FBLNMC was funded by the Savannah River Operations Office of the Department of Energy.

The FBLNMC can be applied to impure samples that range in mass from a few tens of grams to several kilograms of plutonium. The instrument can measure neutronically thin materials such as oxides and residues using a single calibration. Metal buttons require an additional calibration.

DESIGN FEATURES

The FBLNMC evolved from multiplicity neutron detectors^{1,2,3} developed at Los Alamos for impure plutonium samples. The new unit was designed to provide all state-of-the-art features in a single compact package. We designed the FBLNMC using the Monte Carlo Code for Neutron and Photon Transport (MCNP) to perform the Monte Carlo neutron calculations.⁴ The design goals for the FBLNMC were

1. high efficiency (primary importance),
2. uniform efficiency vs sample height,
3. small die-away time,
4. flat energy response,
5. short deadtime, and
6. minimum overall size and weight.

The first four of these design goals work in opposition to the last one.

DESIGN FEATURES
(cont.)

Figure 1 shows a schematic diagram of the FBLNMC design with the 113 ³He tubes surrounding the 20-cm-diameter sample cavity. The outer dimensions of the polyethylene (CH₂) shield are 66 by 66 by 80 cm. The total height is 92 cm.

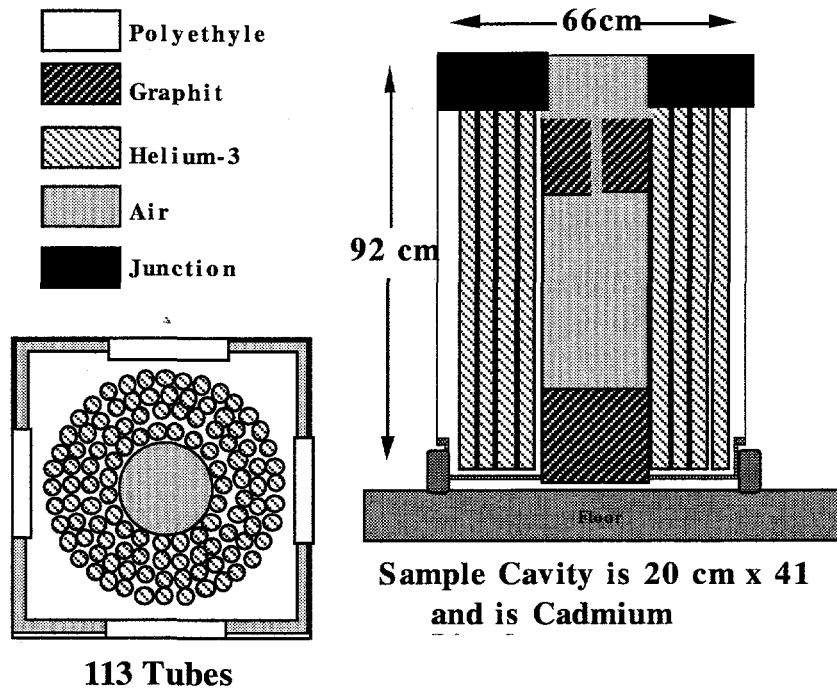


Fig. 1. Schematic diagram of the FBLNMC showing the location of the 113 ³He tubes and the graphite end plugs. The sample cavity height is 41 cm and the diameter is 20 cm.

DESIGN FEATURES

(cont.)

The sample cavity is lined with cadmium (0.8 mm thick) to prevent thermalized neutrons from returning from the CH₂ to the sample and to shield the ³He tubes from a possible high-intensity gamma-ray dose. There is no cadmium on the outside of the detector rings to reduce room-background levels. MCNP calculations⁵ have shown that cadmium reduces the totals background rate by only ~16%. However, the cadmium introduces its own background of coincident neutrons from cosmic-ray spallations and this is detrimental to assays of low mass samples. The end plugs shown in Fig. 1 are made of graphite to scatter the fast neutrons from the end zones back into the CH₂ detector volume.

The MCNP calculation of the response of the detector system as a function of neutron energy is shown in Fig. 2 along with the comparison curve from the Pyrochemical Counter.² The majority of spontaneous fission and (α,n) reaction neutrons have energies in the range of 0.5–2 MeV. Certain impurities such as magnesium and beryllium produce (α,n) reaction neutrons that have higher energies. Assays of samples containing large quantities of these impurities may require additional corrections.

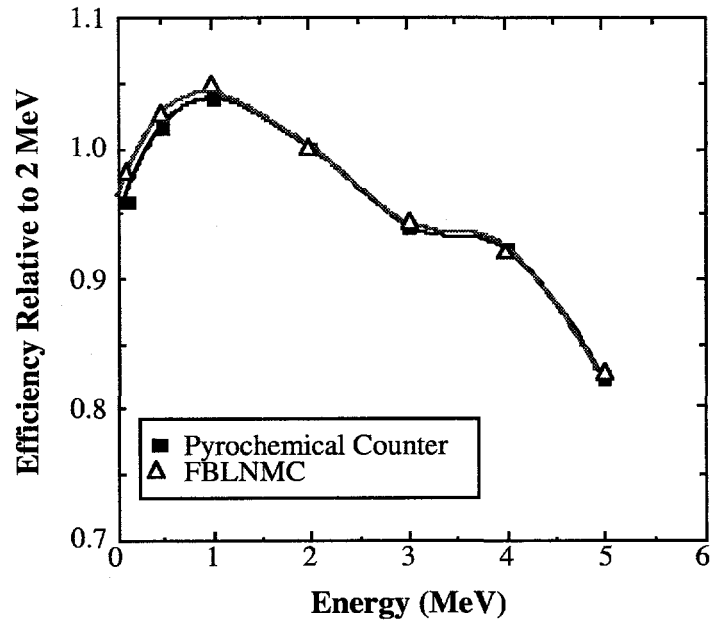


Fig. 2. MCNP calculations of the efficiency vs the neutron energy for the FBLNMC and the Pyrochemical Counter.²

DETECTOR DESCRIPTION

The 113 ^3He tubes have an active length of 71 cm with the specifications given in Table I. The ^3He tubes are connected to the AMPTEK amplifiers.⁶ To give approximately equal counting rates to each AMPTEK amplifier, fewer tubes are connected to each amplifier for the inside tube ring than for the outer rings. For example, one amplifier services three or four tubes on the innermost ring and seven tubes on the outside ring.

Table I. Helium-3 Tube Parameters	
Model	RS-P4-0828-101
Active length	71 cm
Diameter	2.54 cm
Fill pressure	4 atm
Gas quench	Argon + CH_4
Cladding	Aluminum
Operating voltage	1680 V

The 24 AMPTEK amplifiers used with the FBLNMC are shown in Fig. 3. Each of the 24 amplifiers has a digital output signal that causes a light-emitting diode to blink. Figure 3 also shows the cutouts for the four removable desiccant tubes used to keep the detector high-voltage junction box dry.

DETECTOR DESCRIPTION
(cont.)

All of the components for FBLNMC detector head are shown in Fig. 4.



Fig. 3 Photograph of the high-voltage junction box including the AMPTEK boards.

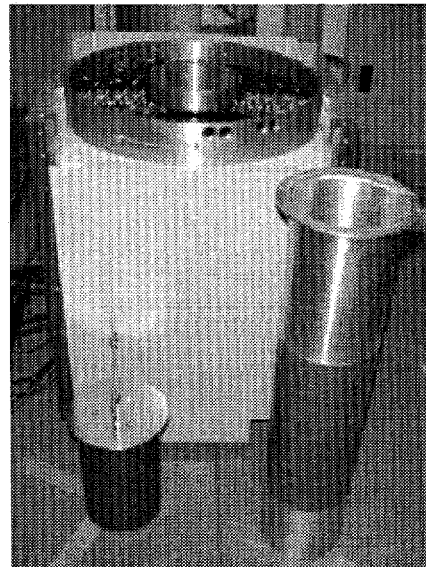


Fig. 4. Photograph of the FBLNMC components.

DETECTOR DESCRIPTION

(cont.)

The detector design includes two improvements over commercial multiplicity counters: a derandomizer circuit and an output from each individual ring of the detector. The former⁷ reduces the deadtime of the counter by more than a factor of 2. The latter provides input to two auxiliary scalars that can be used to diagnose sample anomalies.⁸ Figure 5 shows the relative rates as a function of energy that calculations predict each ring will detect. Figure 6 gives the calculated ratio of the rates in the inner ring to that of outer rings. This ratio provides a sensitive indication of the mean energy of the neutrons emitted by a sample and is strongly influenced by sample moderator or (α,n) reaction neutrons from many low atomic number impurities.

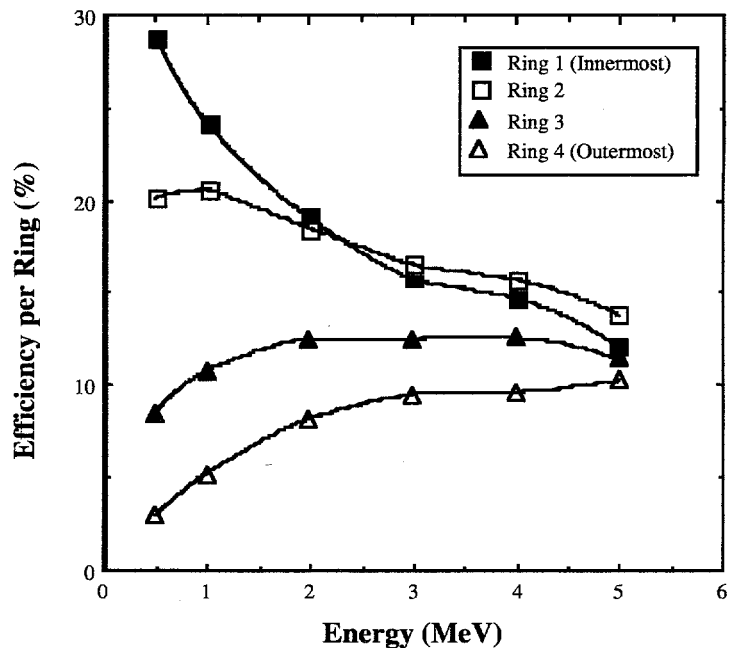


Fig. 5. Relative ring responses of the FBLNMC.

DETECTOR DESCRIPTION

(cont.)

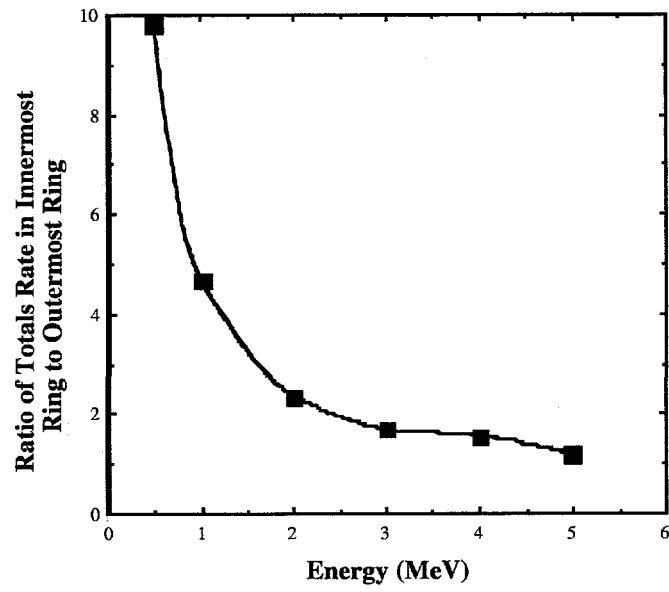


Fig. 6. The ratio of counts in the innermost ring of the FBLNMC to the outermost ring.

GENERAL

A series of measurements was taken to evaluate the performance of the detector. They consisted of measuring the high-voltage plateau, the neutron die-away time, the deadtime, and the absolute efficiency of the detector.

HIGH-VOLTAGE PLATEAU

The high-voltage plateau was measured with ^{252}Cf source. The high voltage was started at 1500 V and incremented by 20 V for each successive measurement until 1900 V was reached. At each voltage, the totals rate was measured. The data are shown in Fig. 7. The knee occurred at 1640 V. The operating voltage is shown to be 1680 V, 40 V above the knee.

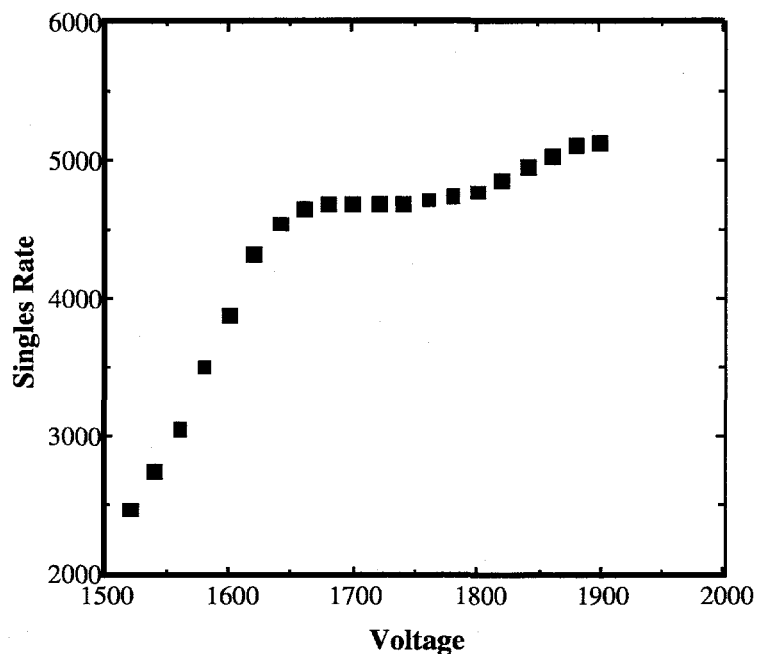


Fig. 7. High-voltage plateau for the FBLNMC.

DIE-AWAY TIME

We used a ^{252}Cf source and gate settings ranging from 8 to 128 μs to measure the average die-away time of the FBLNMC to be

$$\tau = 50.4 \mu\text{s} .$$

DETECTOR DEADTIME

The FBLNMC can be used in both the conventional (two-parameter) coincidence counting mode and in the multiplicity mode. The deadtime considerations are much more complex for the multiplicity mode.

For the simple coincidence mode, the deadtime coefficient δ is given by

$$\delta = (a + bT \cdot 10^{-6}) \mu\text{s} ,$$

where T is the measured totals rate in counts/s and a and b are constants given in Table II with other preliminary calibration parameters. The corrected counting rates are

$$T(\text{corr.}) = T e^{\delta T / 4}$$

and

$$R(\text{corr.}) = R e^{\delta T} .$$

It is important to use the same deadtime coefficients for both calibration and assay so that any errors in the correction will cancel to a first approximation.

DETECTOR DEADTIME
(cont.)

Table II. FBLNMC Preliminary Calibration Parameters	
Parameter	
Efficiency	56.65
Die-away time (center)	50.4 μ s
Predelay	3 μ s
GateWidth	32 μ s
High voltage	1680 V
Deadtime Coefficient a	0.2102 μ s
Deadtime Coefficient b	0.0020 μ s
Multiplicity Deadtime	50.0 ns
Doubles Gate Fraction	0.4426
Triples Gate Fraction	0.1919

MULTIPLICITY DEADTIME

For multiplicity analysis, the deadtime corrections are done with the equations derived by Dytlewski⁹ using a constant deadtime d . The value of d was determined by measuring several ^{252}Cf sources with different neutron source strengths. The triples/doubles multiplicity ratio should be independent of the neutron source strength after deadtime correction. The value of d that gave the best average was

$$d = 50.0 \text{ ns.}$$

EFFICIENCY

The efficiency for the FBLNMC was measured using a calibrated ^{252}Cf source, and the result was

$$\epsilon = 57.8\%.$$

The efficiency measurement was also measured with plutonium oxide standards, and the result was

$$\epsilon = 56.7\%.$$

AXIAL PROFILES

The axial efficiency profile (see Fig. 8) varies by less than $\pm 2\%$ over the height (41 cm) of the cavity and the coincidence (doubles) profile falls within the $\pm 2\%$ boundaries over practical sample fill heights. Of course, the integral response for a can of plutonium has less variation than the measured ^{252}Cf point source.

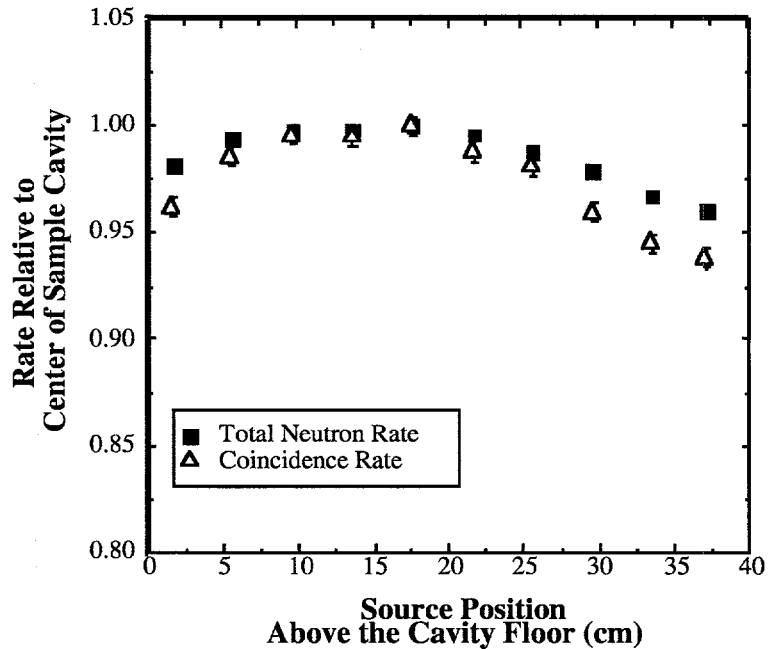


Fig. 8. Measured reals and totals rates as a function of distance above the bottom of the sample cavity.

RADIAL PROFILES

The same ^{252}Cf source was used to measure the radial response variation at the midplane of the sample cavity. The results are shown in Fig. 9 for the totals and reals rates. The efficiency variation is 1.5% over the 16-cm can diameter. In general, the sample can should be centered in the cavity and the integral radial variations will be $< 1\%$.

RADIAL PROFILES
(cont.)

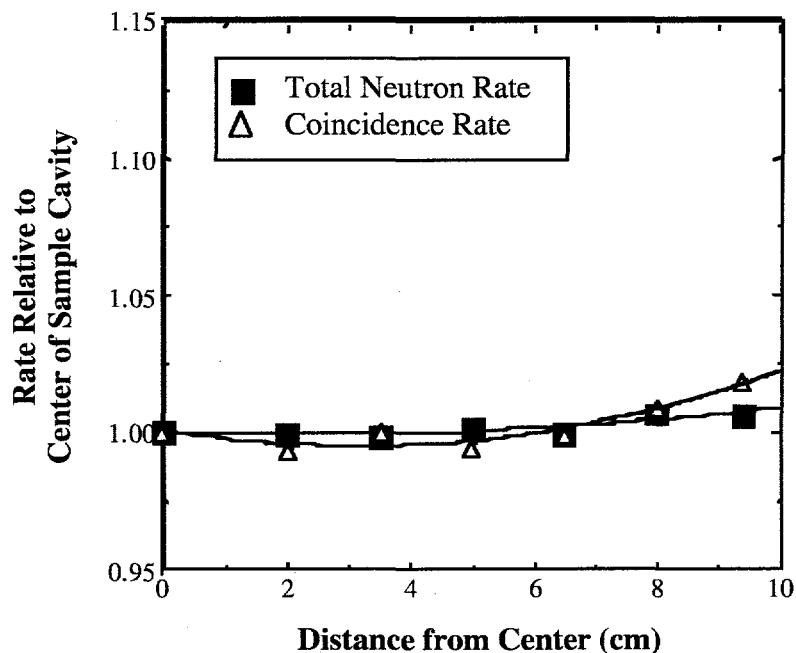


Fig. 9. Measured reals and totals rates as a function of radius from the center of the sample can.

PRECALIBRATION

For the conventional two-parameter "Known α "¹⁰ analysis of neutron coincidence data, it is useful to define the multiplication constant ρ_0 where

$$\rho_0 = R (1 + \alpha) / T \quad (\text{for a nonmultiplying sample}),$$

where α is the calculated ratio of alpha-particle-induced neutrons to spontaneous-fission neutrons.

Small plutonium oxide standards were used to measure ρ_0 , giving

$$\rho_0 = 0.23$$

PRECALIBRATION
(cont.)

for a predelay of 3.0 μ s and a gate length of 32 μ s.

The multiplicity analysis does not use the ρ_0 constant.

We used several of the standard LAO PuO₂ standards to complete a preliminary calibration of the FBLNMC. The multiplication-corrected reals response is described by a straight line through the origin

$$R = a M_{240} ,$$

where $a = 140.1$ and M_{240} is the ²⁴⁰Pu-effective mass in grams.

$$M_{240} = 2.52 \text{ }^{238}\text{Pu} + \text{}^{240}\text{Pu} + 1.68 \text{ }^{242}\text{Pu} .$$

We then measured both LAO and PEO samples in the FBLNMC. The conventional assay results are presented in Table III; multiplicity assay results are presented in Table IV. Note how the impure PEO assays are substantially improved with the multiplicity analysis relative to the conventional "Known Alpha" method. These data are summarized in Fig. 10.

Table III. Conventional "Known Alpha" Results			
Standard	²⁴⁰ Pu-effective mass (g)	Conventional Assay/Reference	1 sigma
PEO382a	1.979	1.156	0.001
LAO250c10	10.11	1.007	0.001
LAO251c11	29.33	1.000	0.001
PEO447	81.45	1.061	0.001
LAO261c11	149.3	0.997	0.001
LAO261c11 & PEO447	230.7	0.999	0.001

PRECALIBRATION

(cont.)

Table IV. Multiplicity Results			
Standard	²⁴⁰ Pu-effective mass (g)	Multiplicity Assay/Reference	1 sigma
PEO382a	1.979	0.997	0.002
LAO250c10	10.11	1.001	0.002
LAO251c11	29.33	1.001	0.001
PEO447	81.45	1.000	0.001
LAO261c11	149.3	1.002	0.001
LAO261c11 & PEO447	230.7	0.997	0.002

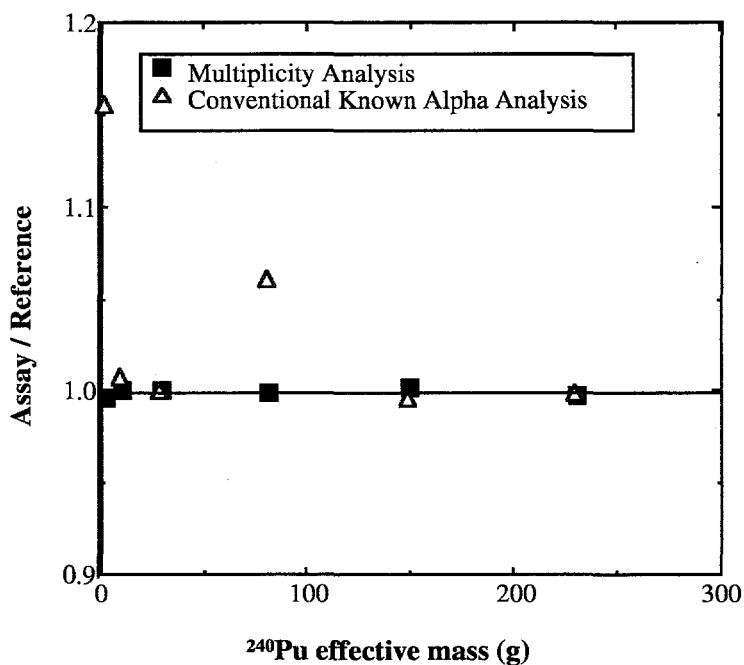


Fig. 10. Assay comparison between conventional and multiplicity assays for FBLNMC.

EXPECTED PRECISION

The FBLNMC was designed to be highly efficient to give good counting statistical precision on the triples counts in reasonable time intervals. Figure-of-merit (FOM) calculations¹¹ were performed to predict the expected precision from counting statistics for this multiplicity counter. The results of these are shown in Fig. 11. The actual performance of this detector will also depend on the precision of the isotopic ratios input to it to convert ²⁴⁰Pu-effective mass to total plutonium mass.

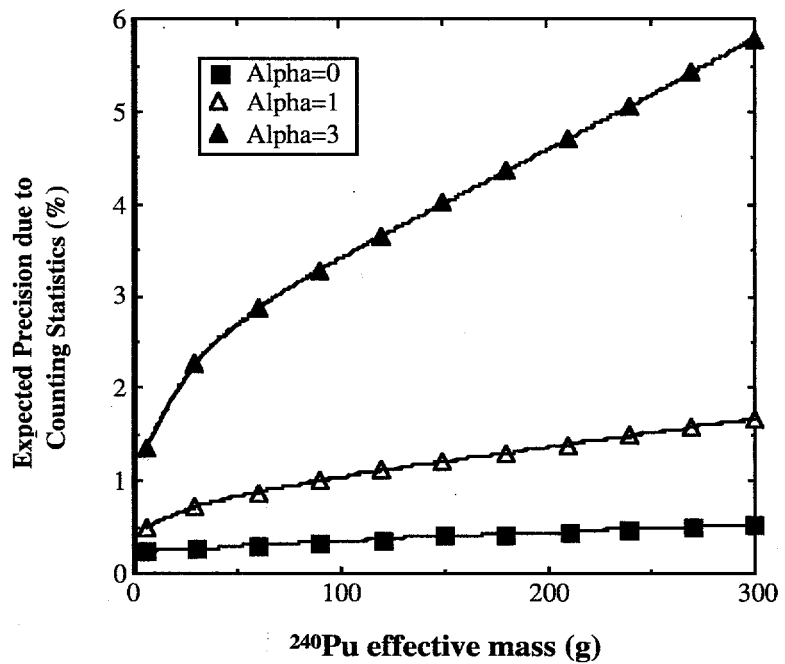


Fig. 11. The expected precision for the FBLNMC for a 30-minute count time.

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