THE AAEC TOTAL BODY NITROGEN FACILITY

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ABSTRACT

A neutron interogation facility has been established at the Lucas Heights Research Laboratories for the in vivo determination of total body nitrogen in malnourished patients. Design parameters of the TBN facility are discussed, with respect to optimisation of nitrogen count rates and reduction of backgrounds. Operational features are described. The facility is used in collaborative studies of cystic fibrosis with the Royal Alexandra Hospital for Children, and of chronic haemodialysis with Royal Prince Alfred Hospital.

1. INTRODUCTION

Lean body mass is an important prognostic indicator for malnourished patients with cystic fibrosis or renal disease. Some 63% of total body nitrogen (TBN) is found as intracellular protein in muscle and viscera. The change in TBN during supplementary nutritional programs therefore provides a direct measure of the lean body mass. However an improved understanding of body composition and protein metabolism is needed in malnourished patients so as to optimise expensive and invasive nutritional support.

The TBN technique was first developed by Biggin et al.[1] at Birmingham using 2-6 MeV cyclotron neutrons. Later isotopic neutron sources were used by Mernagh et al.[2] at Toronto, Vartsky et al.[3] at Brookhaven, and most recently, Beddoe et al.[4] at Auckland. Although the $^{14}N(n,2n)^{13}N$ reaction can be used to produce the positron emitter ^{13}N with 10 minute half life, the prompt neutron capture reaction $^{14}N(n,\gamma)^{15}N$ requires only a neutron source and permits the TBN facility to be installed in a hospital. Further the capture reaction gives a more uniform nitrogen sensitivity with tissue depth, because of the 11.3 MeV threshold for the (n,2n) reaction. Complications also arise in this reaction from interference with other (n,2n) reactions with oxygen, phosphorus, chlorine and potassium.

About 15% of nitrogen capture γ-rays correspond to ground state transitions, with energy 10.83 MeV. This high energy gamma can be readily detected above the background with NaI detectors. However it is important to minimise background count rates.

2. NEUTRON SOURCES

Measurements were made with ^{238}Pu-Be, ^{239}Pu-Be and ^{252}Cf neutron sources, using a well shielded 200 x 150 mm NaI detector and a 6 L phantom with 4.7 mol L^{-1} NH_4Oh, about twice the tissue equivalent nitrogen concentration. Source

parameters and nitrogen to background ratios for the same shielding geometry are given in Table 1.

TABLE 1
COMPARATIVE DATA FOR NEUTRON SOURCES

Source		^{239}Pu-Be	^{238}Pu-Be	^{252}Cf
REACTION		(α,n)	(α,n)	Fission
$\langle E_N \rangle$	(MeV)	4.5	4.5	2.13
Activity	(Ci)	10	11.5	3.0×10^{-3}
ϕ_N	(s^{-1})	1.5×10^7	2×10^7	1.7×10^7
SSD	(mm)	305	305 405	305 405
Net neutron yield*	Δ	2000	2800 1400	1900 1050
Uncertainty*	(%)	6.6	6.0 7.4	3.8 4.8
Background:*	(NBG)	7600	12900 4500	1500 730
	Δ/NBG	0.26	0.22 0.31	1.27 1.44
Dose equivalent	(mrem h^{-1})	110	170 120	90 65
Yield per dose	Δ/D	18	17 12	21 16

* For 1000 s exposure

The ^{252}Cf fission source gives the most accurate and highest signal/background ratio, the spectrum being shown in Figure 1. The 2.65 y half-life of ^{252}Cf argues against use of this source, and the fission neutron spectrum is somewhat softer than the Pu-Be sources. However, the neutron distribution in the 12 L phantom is comparable to that for Pu-Be.

These results are confirmed by the data of Morgan et al.[5] who found that the ^{252}Cf source generates nearly 40% more thermal fluence per incident dose equivalent than the ^{238}Pu-Be source.

A further advantage of the Cf source is its small size. A 27 mCi source rated at 2.1×10^8 n s^{-1} has dimensions 8 mm dia. x 10 mm and can be mounted on a 10 mm dia. aluminium rod with boron carbide epoxy filling for transfer from a mobile source drum into the TBN table shield stack.

The disadvantage of the ^{252}Cf source is the relatively short half-life of 2.65 years. However this is probably comparable to the half-life of the project and is offset by the low cost of the source ($6400 AUST.) compared with ~ $2000 AUST. for an equivalent Pu-Be source.

3. NEUTRON SHIELD STACK AND COLLIMATORS

This stack (Figure 2) is constructed of 230 x 230 x 150 mm^3 blocks of borated paraffin (~ 50% boric acid). A wedge shaped collimator (perpendicular to the table axis) increases the incident neutron flux and reduces the average neutron energy at the 230 x 230 mm^2 aperture. Lead bricks are placed at the

ends of the wedge collimator to shield the bilateral NaI detectors. Additional Pb plates are placed at the top of this stack to shield the NaI detectors from gamma rays from the $H(n,\gamma)$ and $^{10}B(n,\alpha\gamma)$ reactions. The dose equivalent at the perimeter of the stack is ~ 2-3 mrem h^{-1} for neutron and gammas. The neutron dosimetry is discussed elsewhere in these proceedings[6].

Existing NaI detectors have been used in this version of the TBN facility. A 200 mm dia. x 150 mm deep crystal with four PM tubes has about twice the nitrogen gamma ray efficiency of a smaller 150 mm dia. x 100 mm deep crystal. However the background under the 10.8 MeV peak is much lower for the smaller detector. This efficiency imbalance requires the accurate and reproducible placement of phantoms and patients. Reproducibility of the net nitrogen yield to 1% is achieved for the static 2000 s exposure of an 8 mol L^{-1} urea standard phantom with dimensions 220 x 440 x 175 mm. This phantom allows normalisation of all results during these trials, and is measured before and after patient exposures. A water phantom of the same volume provides the background subtraction to give the net nitrogen yield.

The linearity of the system has been determined via constant volume phantoms with different urea concentrations ranging from 0.5 to 7 mol N L^{-1}. These data are shown in Figure 3 for each detector. The zero intercept on the ordinate is eliminated after a correction is made for hydrogen substitution by urea at the higher nitrogen concentrations.

4. TABLE MOVEMENT CONTROL

The major requirement of the table operation is to pass the patient over the neutron aperture. A 20 mm thick moving table top on teflon slides is used.

The logical design of the table control is given in Figure 4. Dwell times at 1-4 exposure positions (at 260 mm spacing) over the source can be preset, so that the total exposure time remains constant. A home switch is provided to return the table from any position, and a stop switch will freeze the table movement at any time. A 1/4 HP, 3 phase motor is geared down (X900) to turn a 340 mm dia. cable wheel. The table top is then moved by cable, winding in the clockwise or anti-clockwise directions. Table cycle time is reproducible to better than 1 second in 420 (0.2%). Some problems were initially experienced with interference between 3 phase switching at the logic circuitry. However, this has been overcome with the current design.

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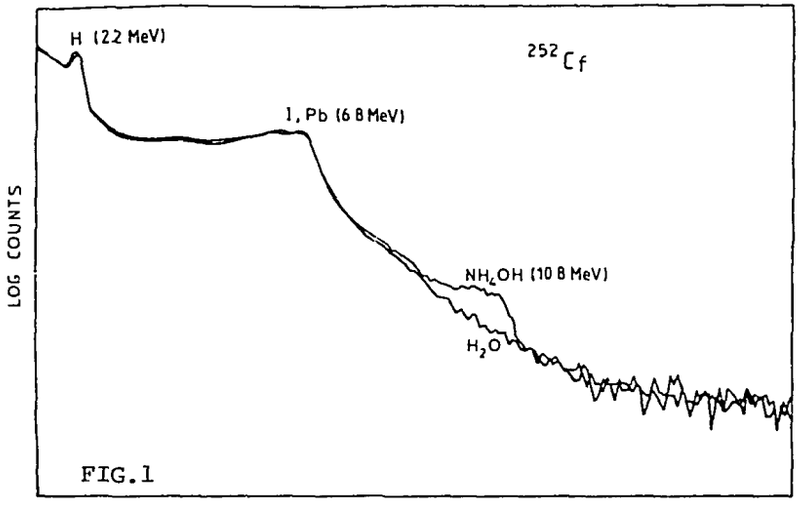
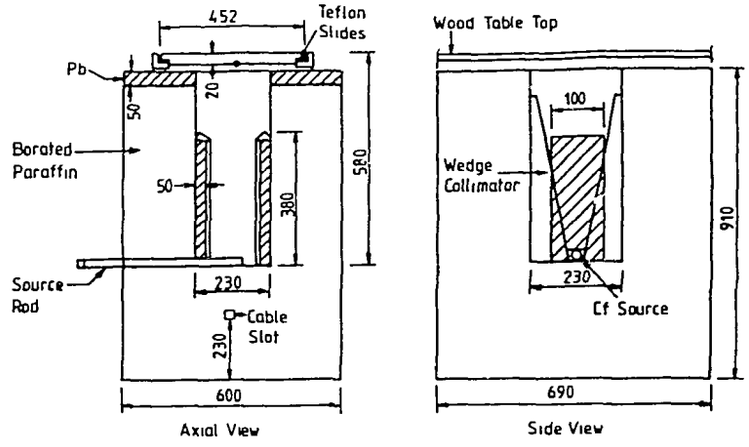


FIG.1



SHIELD STACK AND COLLIMATOR (mm)

FIG.2

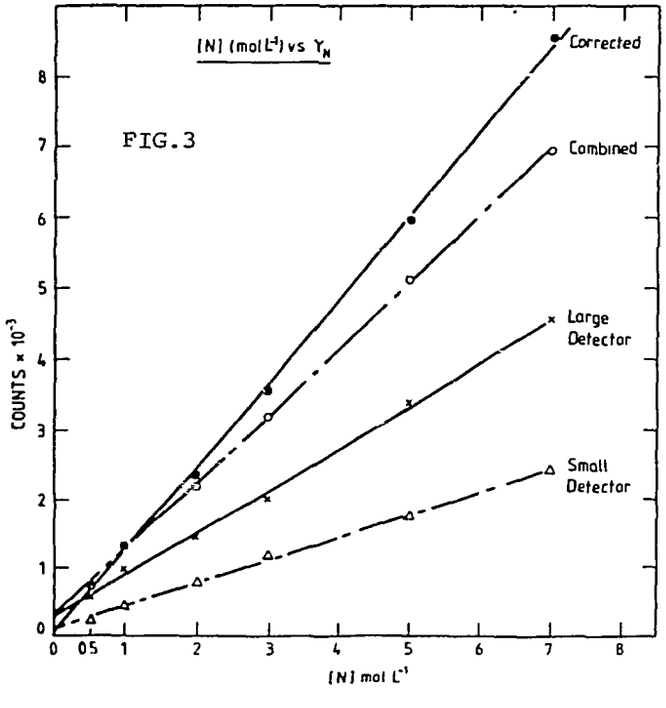


FIG.3

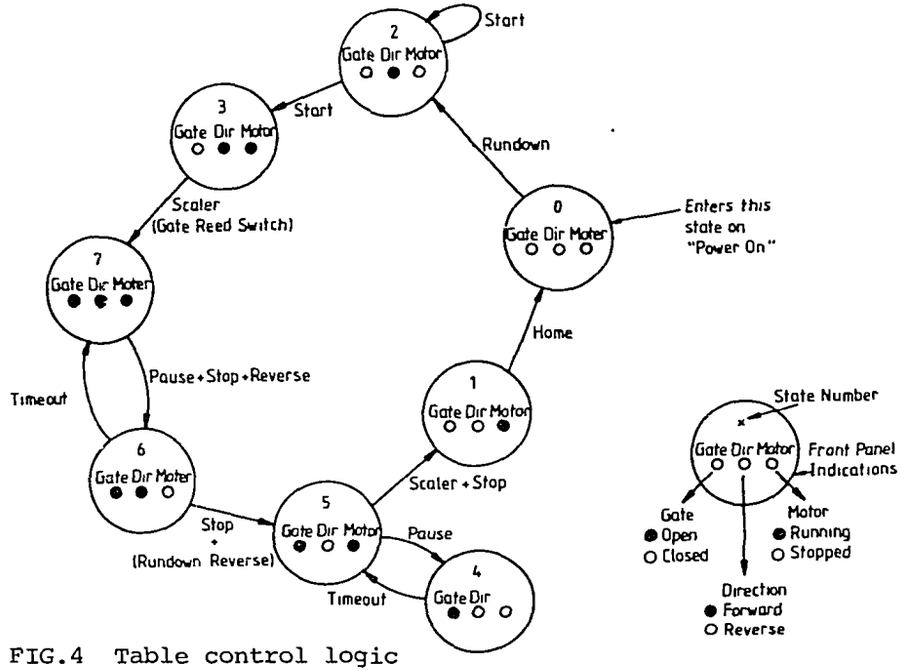


FIG.4 Table control logic