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PROGRESS REPORT ON A FAST NEUTRON FACILITY

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ABSTRACT

Work towards the installation of a fast neutron facility at Instituto de Engenharia Nuclear, is under way. This facility will use the available variable energy deuteron beam of our CV-28 cyclotron to produce "monoenergetic" neutrons in the range from 5 to 14 MeV by the $D(d,n)^{3}He$ reaction.

Progress so far achieved in this initiated in 1982 project is described in this report.

RESUMO

Montagem de um arranjo experimental para produção de nêutrons rápidos no Instituto de Engenharia Nuclear está em andamento. Esta instalação experimental usará o feixe de dêuterons de energia variável de nosso ciclotron CV-28 para produzir nêutrons "monoenergéticos" entre 5 e 14 MeV pela reação $D(d,n)^{3}He$.

Progresso alcançado neste projeto iniciado em 1982 é descrito neste relatório.

1. INTRODUCTION

During the last 50 years, since Chadwick's discovery of the neutron, generations of physicists have dedicated their lifetimes to the study of the interaction of this particle with matter. The requirements for nuclear energy generation have resulted in a world effort in gathering neutron nuclear data, as exemplified by the CINDA[1] publications. Hardly a piece of data sought can not be found there, for most practical uses.

However, despite this huge amount of data already available, still more data are in need, many in the neutron energy range from 5 to 14 MeV which is an interval that can be covered with some ease by the D(d,n)^{3}He reaction, in a medium energy cyclotron as our CV-28, for instance.

This accelerator, whose characteristics have been described elsewhere[2], has been in operation since 1975. It is a multi-purpose machine and so far it has been used mainly for radioisotope production for medical purposes and basic nuclear physics. Recently, partly motivated by the IAEA Interregional Project, it was decided that some of the beam time should be devoted to fast neutron nuclear data acquisition, and a new beam transport system is being built in consequence.

In this paper, after a description of the experimental area of the facility, we report on extensive studies done already on two NE-213 detector characteristics. Next our gaseous D target is described and future plans are presented.

2. EXPERIMENTAL ARRANGEMENT

A lay-out of the fast neutron experimental area is shown in figure 1. The beam coming out of the switching magnet will be focused onto the D gas target via two quadrupole doublet magnetic lenses constructed according to a project by the Physics Institute of UFRJ[3]. On this beam line, beam control will be achieved with the help of a 19" ORTEC scattering chamber for energy measurements and current monitoring, and a DANFYSIK beam monitor system consisting of a beam scanner for beam alignment and adjustment and a Faraday cup that can intercept the beam via a pneumatic actuator, for beam current measurements. An independent 4" diffusion pump vacuum system is connected to this beam line. A gate valve is located before the scattering chamber to allow isolation of the beam pipe leading to the cyclotron, for maintenance purposes.

Two NE-213 detectors at fixed positions are used. One at 0º to the beam line, for neutron energy and flux measurements behind a hole in a 30 cm parafin and 60 cm concrete wall which will both collimate the fast neutron beam and shield the gamma-rays and scattered neutrons coming out of the target region. The second detector is positioned 60º to the beam for monitoring purposes during irradiations.

3. NEUTRON DETECTORS

The detectors, Nuclear Enterprises BA1 type NE-213 liquid scintillators to be used in the pulse shape analysis method, are 1 1/2" x 1 1/2" ϕ and 2" x 2" ϕ, the smaller one to be used at 0º and the larger one as a monitor at 60º to the beam line. They are assembled in designed to be simple housings which hold the detector, the light pipe, the photomultiplier, the voltage divider, the magnetic shield and a light emiting diode pulser useful for checking linearity. A cut away drawing of the assembly for the smaller detector is shown in figure 2.

Using standard gamma-ray sources, the light pulser and a voltage pulser, the resolution of both detector systems were already measured at IEN, while the smaller one is also being tested for resolution at the PTB in Braunschweig, using the more advanced facilities there, like energy measurements by time-of-flight, multiparametric analysis, computer codes etc.

In the IEN experiments, conventional ORTEC NIM electronics were used, viz., pulse shape analyser 552, pre-amplifier 113, time to pulse height converter 467, double delay line amplifier 460, and high voltage power supply 456. The data were stored either in an old HP multichannel analyser whose data can be output into an HP-85 computer for analysis, or in a new 3500 M Le Croy MCA. This CAMAC based MCA is a powerfull stand alone data acquisition and analysis system with enough storing and computing memory for most tasks required in radioactivity measurements.

In these experiments, the system resolution for gamma-rays is being determined according to methods described by Dietze and Klein[4]. The resolution is described empirically by:

$$\frac{\Delta L}{L} = (A^2 + B^2/L + C^2/L^2)^{1/2} \qquad (3.1)$$

ΔL being the FWHM of the output signal L. This resolution singles out the following elements in the output pulse:

- The dependence of light collection on the position of interaction of the gamma-ray in the detector, A
- The statistical behaviour of the detection process, B
- The overall electronic noise, C.

Klein and Schölermann[5] have improved the light collection characteristics of cylindrical NE-213 detectors by the use of a partially coated light pipe between the detector and the photocathode of the photomultiplier tube: this has resulted in a response of the detector which is almost independent of the point of interaction of the gamma-ray, and therefore in a very small A for the whole diameter of the detector. The A values for the detectors were obtained by scanning the entrance surface of each detector with a ^{137}Cs source well collimated thru a 2 mm hole in a 5 cm lead shield. After each count, lasting for 30 min, the source was moved radially by 5 mm. In order to subtract also the radiations that reach the detector after traversing the 5 cm lead collimator, one 30 min background counting was obtained with the same ^{137}Cs source behind a 5 cm lead block. This background was then subtracted from each count and it can be seen in figure 3, which is a typical result, that very good and clean Compton spectra were obtained.

In each of these spectra, the Compton edge light output is found and the ratio to the Compton edge light output at the central position is calculated. The results obtained are shown in figure 4 for both detectors and it can be seen that this ratio is practically constant and varies less than 1.5% in all measurements.

The electronic noise was obtained with the help of a BNC pulser, whose signal was fed into the test pulse input of the preamplifier. The pulse height was varied throughout the range of the MCA and the FWHM obtained, in each case, by fitting by iteractive least squares a Gaussian to the data points[6]. The resultant FWHM's were then weighed and averaged by a program that besides can discover discrepant data by comparing internal and external standard deviations[7]. The final C values for the detectors are shown in table 1.

The statistical noise was obtained using a LED pulser[8], whose intensity and repetition rate can be varied simulating different light inputs and count rates. In these experiments, the count rate and time were fixed and the amplitude of the light pulse was varied. Figure 5 shows the results for one of the detectors. For each light output L, the same computer program was utilized to fit a Gaussian through the data points and get the FWHM versus L. The square of FWHM should vary linearly with L, and figure 6 shows that this is indeed the case. The straight line in this figure was obtained by a least square fit program through the weighed experimental data points, the weights being proportional to the inverse of the square of the standard deviations. For each L, B was calculated using expression (3.1), and these B values were then averaged using the aforementioned averaging program and the final result is shown also in table 1.

It is interesting to note that the C^2 value can also be obtained from equation 3.1, as the intercept in a $(\Delta L)^2$ versus L plot, using the light pulser. The C value thus obtained, agrees, within experimental error, with that obtained by using the BNC voltage pulser, for the bigger one, but disagrees with that for the smaller detector. This fact has been interpreted as a contribution to the electronic noise by the dark current of the Hamamatsu photomultiplier used in the 1.5" x 1.5" detector. Further investigation of this effect is under way.

It is worth mentioning that different photomultipliers are used in these detectors. While an R 359 Hamamatsu is incorporated in the assembly shown in figure 2, the bigger detector is using an 8575 RCA photomultiplier.

Figure 7 shows finally the gamma-ray resolution as a function of energy, as calculated by formula (1) using the parameter values of table 1.

System linearity was also checked using some standard gamma-ray sources and two high-energy gamma-rays originated from an Am-Be neutron source, namely 2.2 MeV from the binding energy in D and 4.43 from the first excited state in ^{12}C. Figure 8 shows the data points used and the best fit straight lines, for each detector.

Finally in figure 9 a detector response to neutrons from an Am-Be source is shown. The neutron spectrum from this source will be obtained using this response by a neutron unfolding code, most likely FORIST[9]. Adaptation of this code to our Honeywell-Bull CII-HB L 64 DPS 6 is underway.

4. GASEOUS DEUTERIUM TARGET

The neutrons in the facility will be produced by the $D(d,n)^3He$ reactions, using the variable energy deuteron beam from our CV-28 cyclotron. This accelerator is able to produce copious quantities of energetic d, much more indeed, than is antecipated to be necessary: up to 100 μA of 14 MeV d can be produced. The deuteron energy, that can be continuously varied, cover a wide range from 3 to 14 MeV. Therefore, the neutron energy spans a considerable range, including the "rare" range from 5 to 12 MeV, where data are most needed[10]

The D gas target follows a more or less conventional design(11,12). Thin Mo foil (5 μm) is used as entrance window and thick Au foils as beam stop, in a stainless steel chamber with 0,5 mm walls. The chamber is 30 mm deep and 12 mm in diameter. A cut away drawing can be seen in figure 11. Gas is supplied through a regulator, which sets up the pressure in the chamber. A by-pass allows vacuum to be made in the chamber for "gas out" irradiations.

5. FOLLOW-UP

It is planned to have this facility in operation late this year. After final assembly of the beam line it is foreseen that some time will be necessary for testing and tuning and focusing the beam onto the target.

Efforts will have to be spent into achieving extraction, transport and measurement of the energy of the deuteron beam spanning the sought energy range, with accuracies compatible with present day requirements put on new neutron data measurement. For this task, the monitoring system installed in the beam line is adequate.

Extraction of the neutron monoenergetic lines from the neutron detector responses will be necessarily done by unfolding codes such as FORIST and to guarantee results reliability, our detector will be calibrated in neutron fields at the PTB using the TOF facility existing there.

ACKNOWLEDGEMENTS

This project has been made possible by a sum of happy circunstances to which we are thankful. We thank specially the support received from the IAEA through the Interregional Project, but mostly Dr. J.J. Schmidt and his colleagues of the NDS who have been responsive to our requests. In Dr. H. Klein from PTB we found a friend and a most cooperative expert: may he find here our acknowledgements for all he has done for the completion of this project.

REFERENCES

1. CINDA 83 (1977-1983), IAEA, Vienna (1983).

2. A.G. da Silva and L.T. Auler, in "Nuclear Data for Science and Technology", K.H. Bookhoff (ed.), D. Reidel Publishing Co., Dordrecht, Boston, London, 843 (1983).

3. H.E. Wolf, J. Eichler, S. de Barros and L.F.V. Paiva, report 001/1982 IF/FIN, Universidade Federal do Rio de Janeiro, Brasil (1982).

4. G. Dietze and H. Klein, Nucl. Instr. and Meth., 193(1982) 549.

5. H. Klein and H. Schölermann, IEEE Trans. Nucl. Sci., 26 (1979), 373.

6. L.T. Auler, report DEAT/SF/SFN-2/77, Instituto de Engenharia Nuclear, Rio de Janeiro, Brasil (1977).

7. Yu. I. Grigorian, L.L. Sokolovskis and F.E. Chukreev, INDC(CCP) - 75/LN (1976).

8. H. Klein, private comunication.

9. R.H. Johnson, D.T. Ingersoll, B.W. Wehring and J.J. Dorning, Nucl. Instr. and Meth. 145 (1977) 337.

10. WRENDA 83/84, V. Pksaikin, ed., INDC (SEC)-88/URSF(1884).

11. C.L. Morris and S.T. Thornton, Nucl. Instr. and Meth. 96 (1971) 281.

12. R. Böttger, H.J. Brede. M. Cosack, G. Dietze, R. Jahr, H. Klein, H. Schölermann and B.R.L. Siebert, "Nuclear Data for Science and Technology", K.H. Bockhoff, ed., D. Reidel Publishing Co., Dordrecht, Boston, London, 836 (1983).

Table 1 - Final results for the resolution factors obtained in this work for the two detectors.

Detector dimensions	Resolution factors		
	A(%)	B(%)	C(%)
1.5" x 1.5"	0.6 ± 0.2	6.44 ± 0.05	0.38 ± 0.01
2.0" x 2.0"	1.4 ± 0.5	8.26 ± 0.02	0.51 ± 0.01

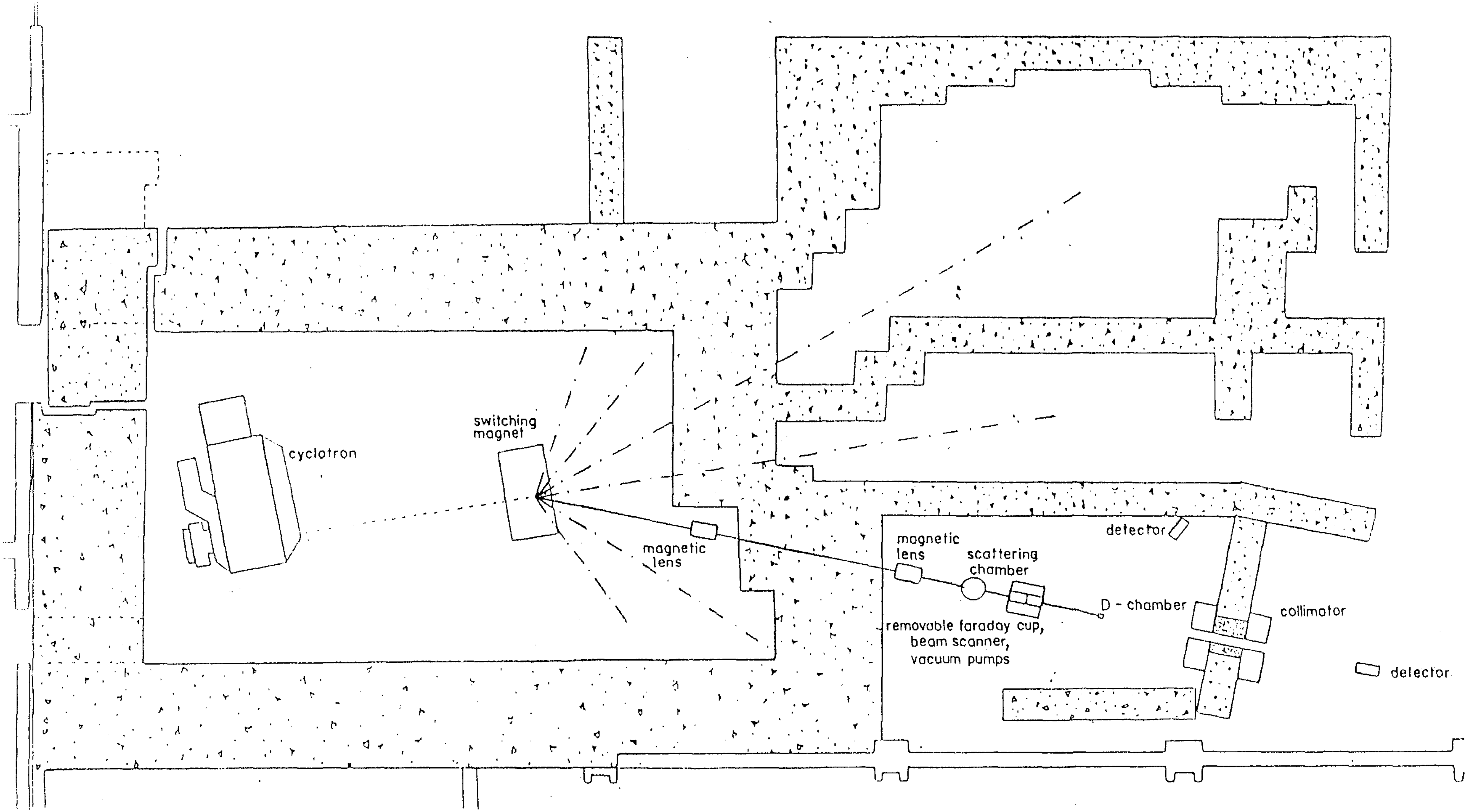

Figure 1 - Lay-out of the experimental area showing the neutron beam line.

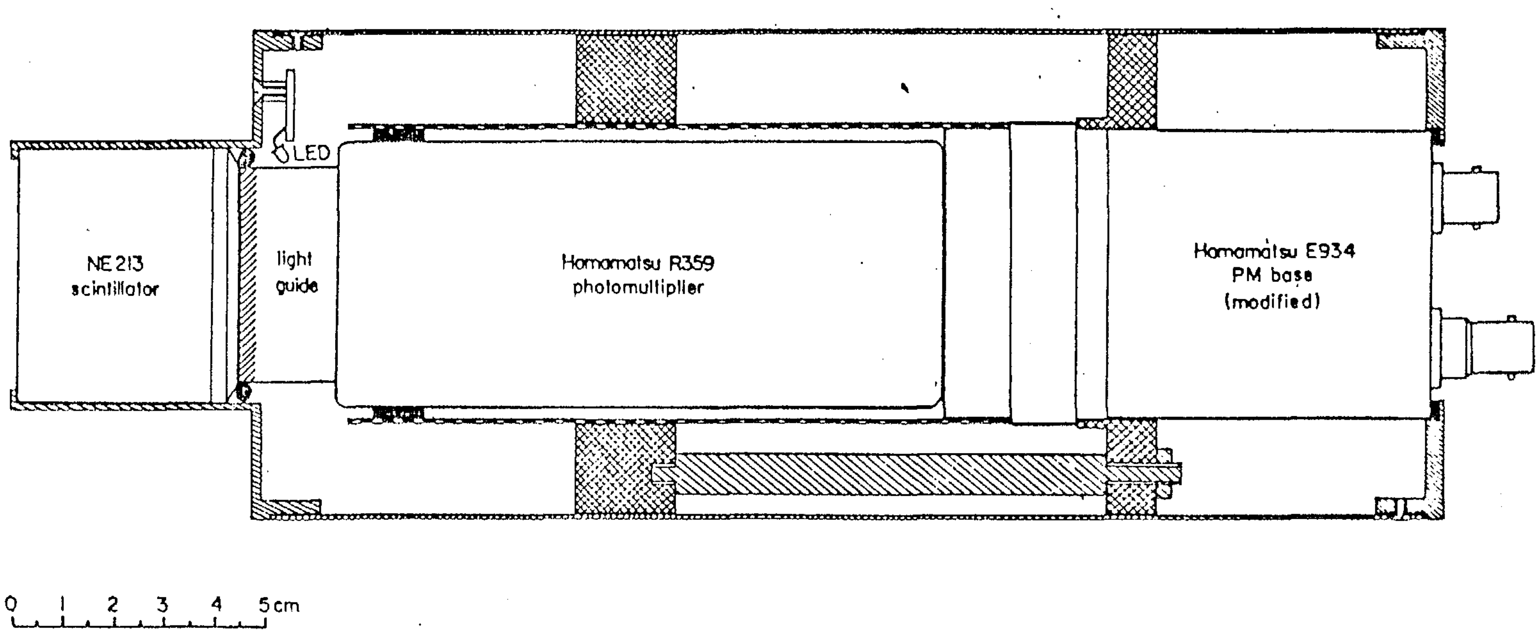

Figure 2 - Cut away view of NE-213 neutron detector assembly. It is made of aluminium on the outside with insulating rings of PVC for centering. The parts are held in place by a pressed O-ring shown at the right end of the drawing.

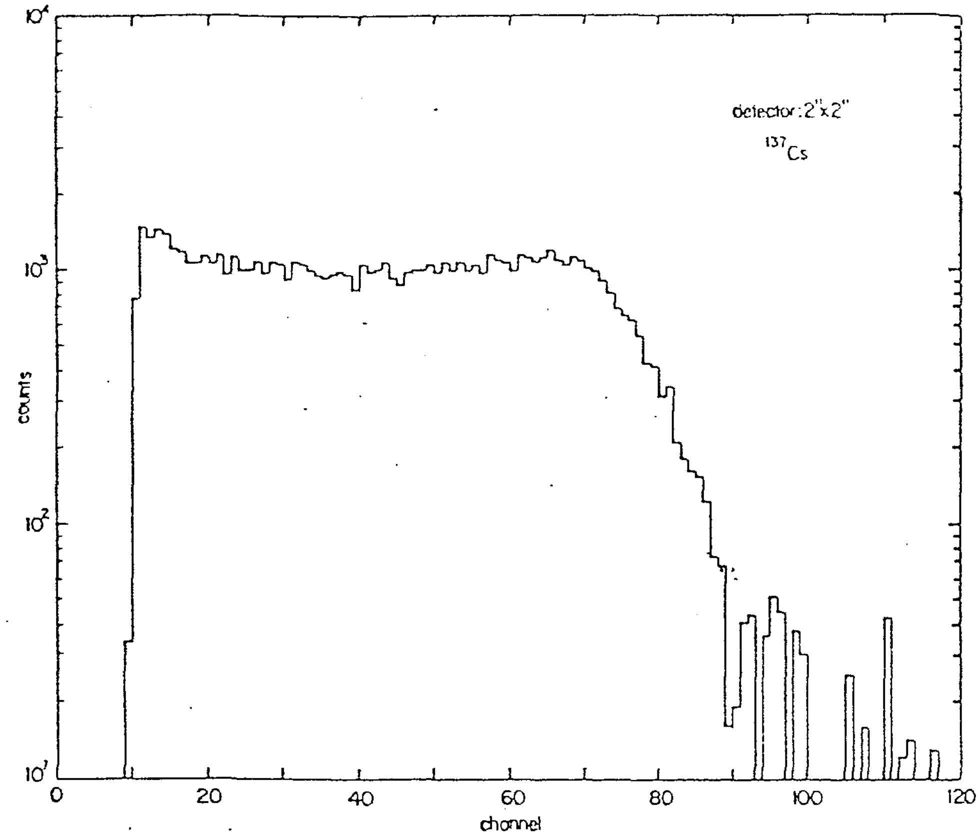

Figure 3 - Background subtracted spectrum of light output using a ^{137}Cs source.

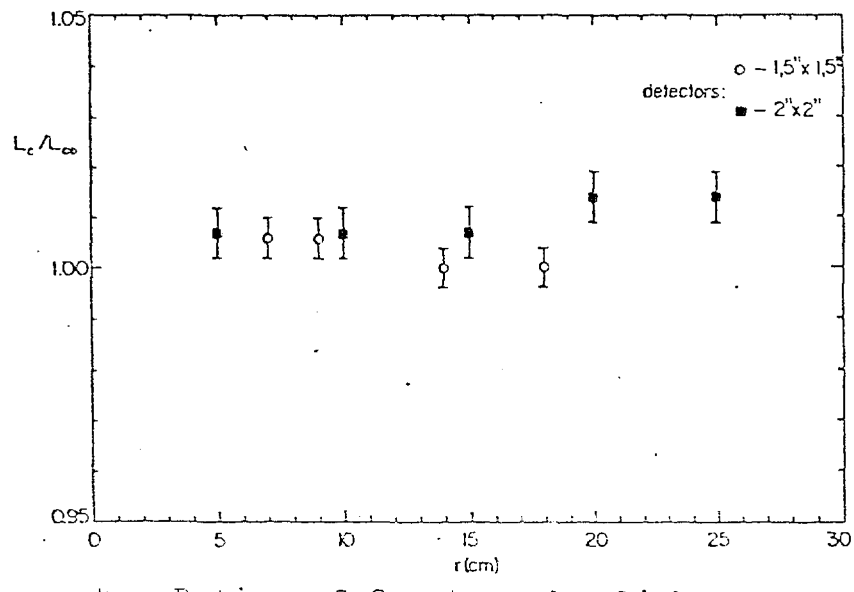

Figure 4 - Ratios of Compton edge light output for incidence at radius r to Compton edge light output for central incidence.

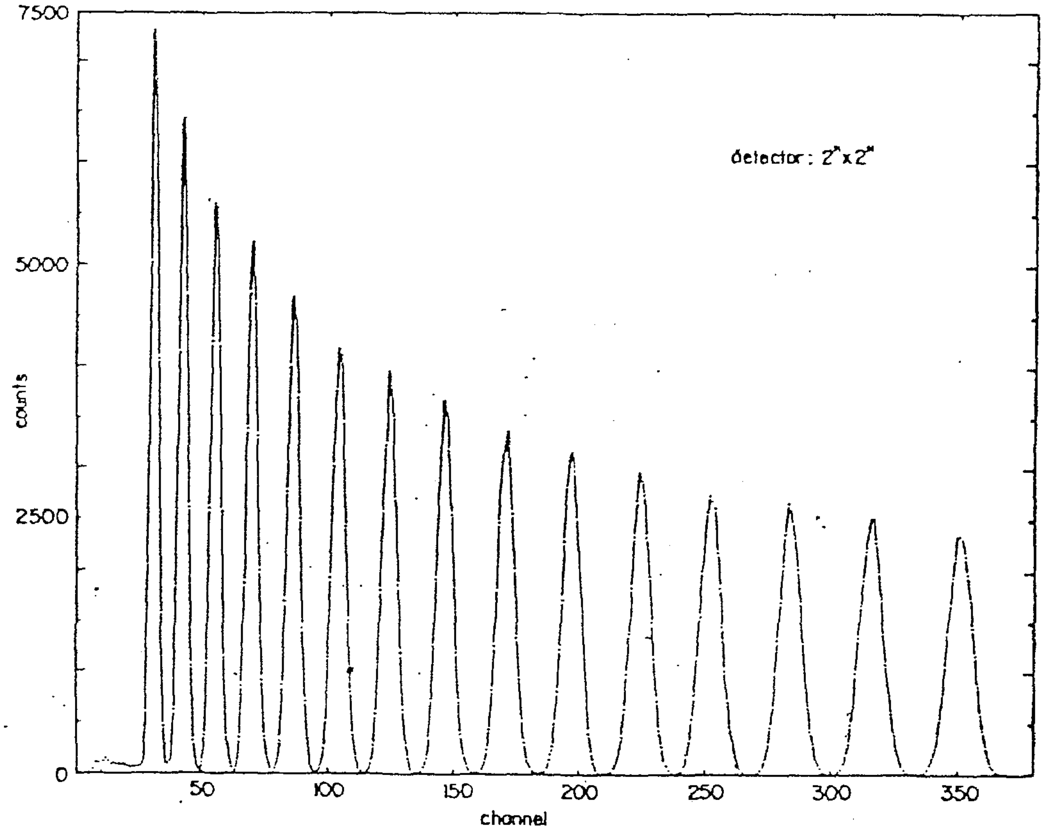

Figure 5 - Detector response to LED pulses

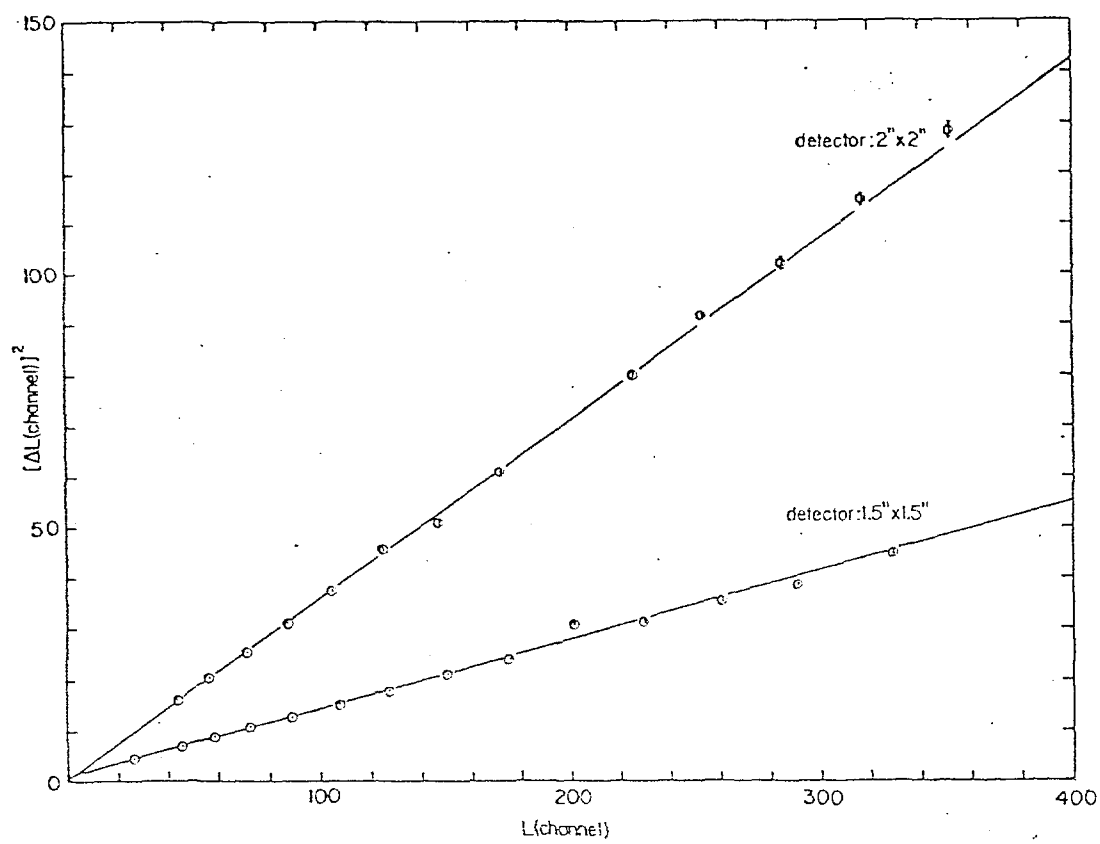

Figure 6 - Squared resolution, $(FWHM)^2$, versus light output obtained using the LED pulser.

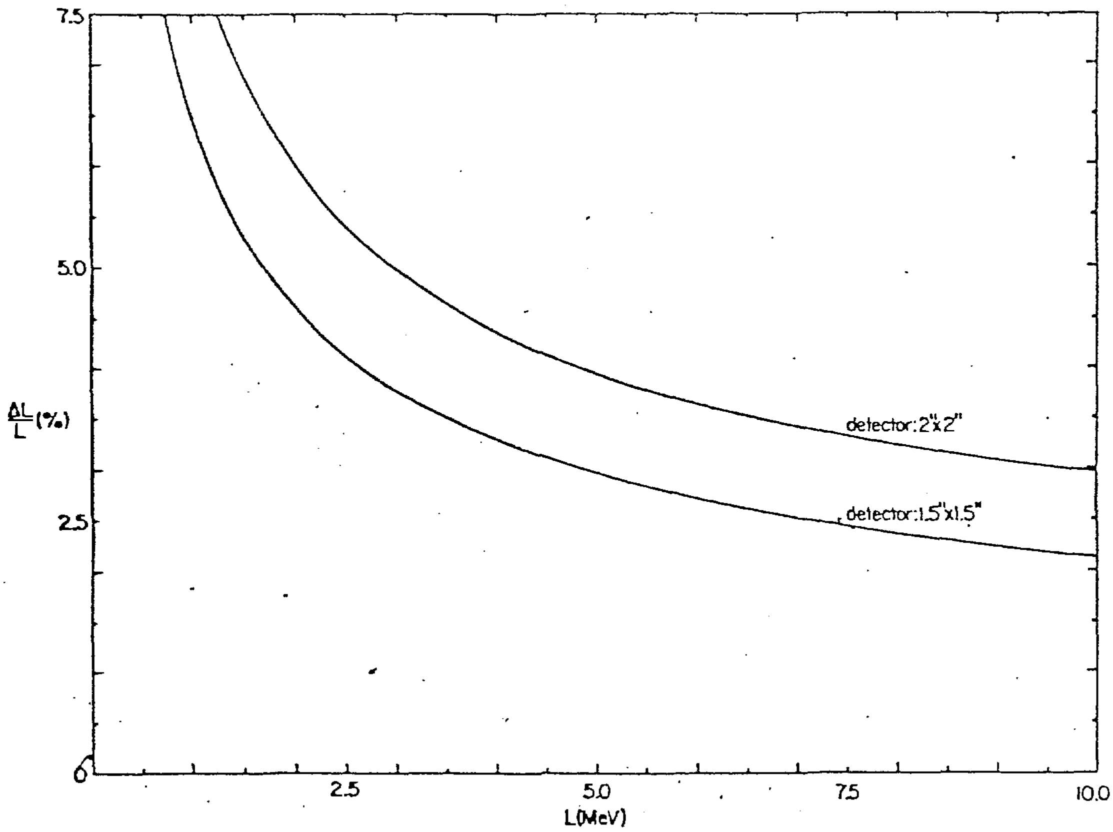

Figure 7 - Resolution function (eq. 3.1) using the parameters given in table 1.

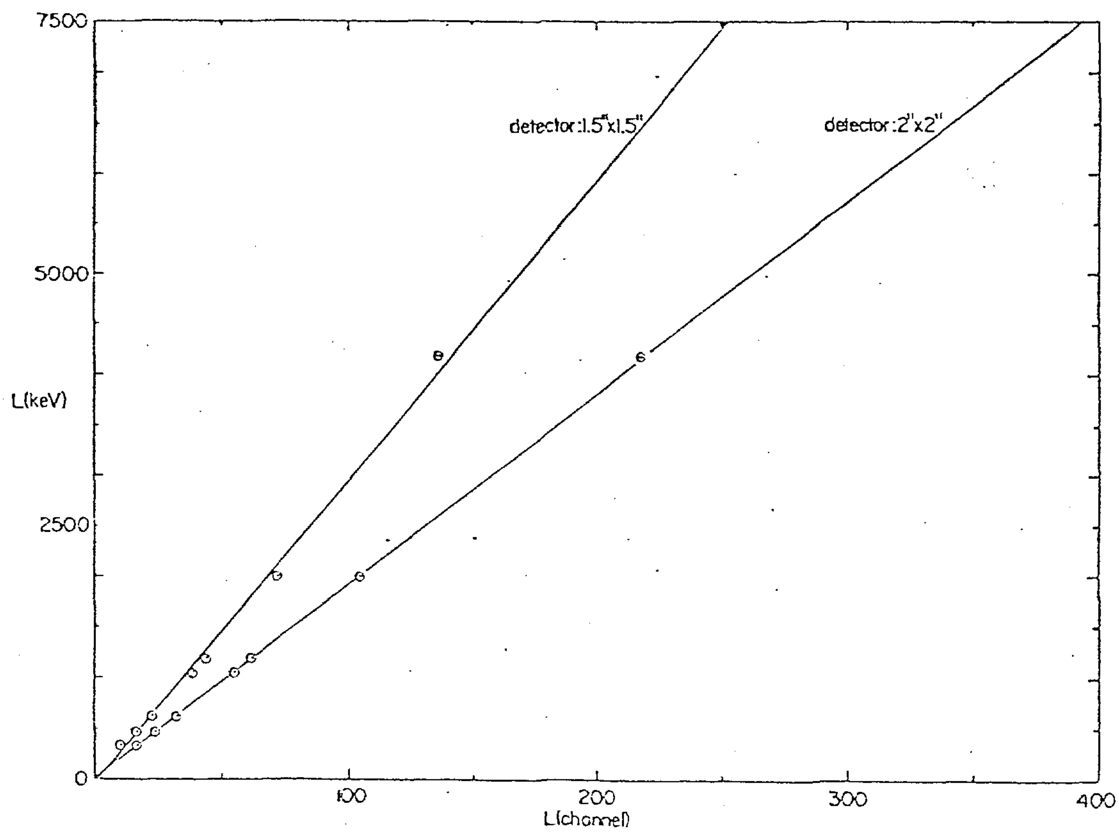

Figure 8 - System linearity as obtained using standard gamma-ray sources.

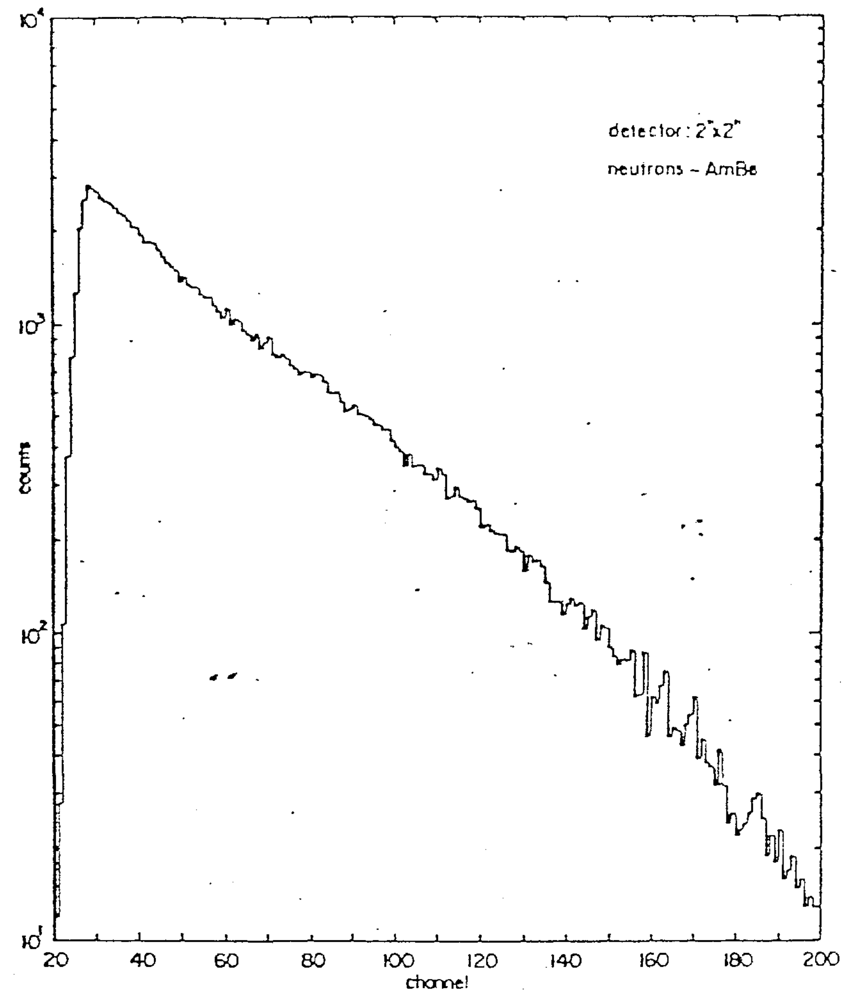

Figure 9 - Detector response to an Am-Be neutron source. This light output spectrum was obtained by the pulse shape discrimination technique.

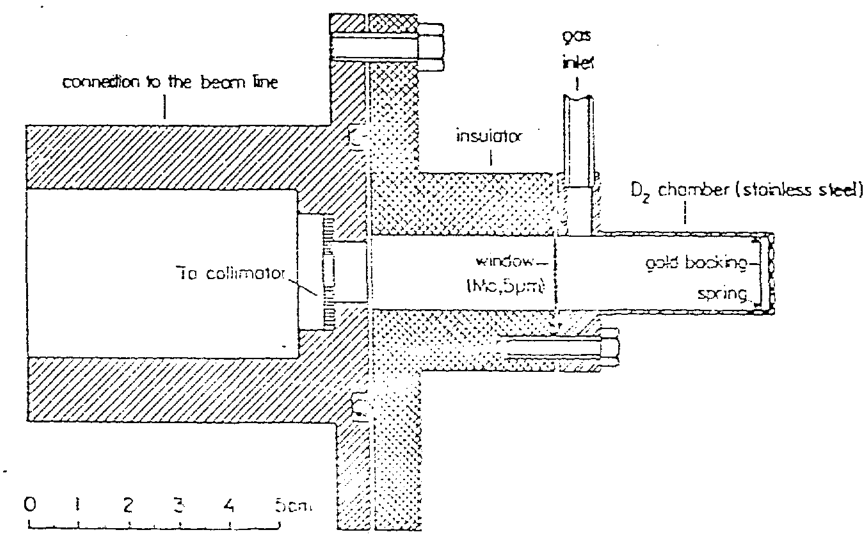

Figure 10 - D-gas target to be used in the facility.