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SOLENOIDAL DETECTOR NOTES

RECOMMENDED ISOTOPES FOR CALORIMETER SOURCE CALIBRATION

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Abstract

The goals of the source calibration system are analysed to derive requirements on the isotope used in the barrel EM and endcap EM calorimeters. The isotope best suited to the requirements is Barium 133. Rhodium 101 may work well in areas other than the barrel EM. Cobalt 57, Cesium 137 and Tin 113 are alternatives if the first two are not available or are found to be unacceptable for other reasons.

Introduction

The source calibration system has three distinct uses:

- to provide quality control (tile testing and longitudinal masking) during assembly, installation and operation;
- to transfer test beam calibration from selected modules to others;
- to monitor stability and provide redundant calibration during operation.

Each of these operations implies a different requirement on the calibration system. For QC/masking, it is necessary to illuminate every tile; ideally, every tile individually. If the tiles were perfectly masked---ie, every tile had exactly the same response as every other one---it would be possible to transfer the calibration from one module to another by illuminating a single tile in each. However, given the variation expected even after masking, it will be necessary to illuminate many tiles. It may be possible to combine the operations of masking and normalization.

During operation, the source calibration monitors the change in response of tiles and fibers both due to radiation damage and due to deterioration which occurs even in the absence of radiation. These changes are expected to affect many tiles in a similar way, so it is sufficient to monitor only a subset of the tiles---a subset that is large enough to provide a statistically significant measurement of the changes. This subset is also sufficient to provide a cross check of the charge injection (front-end electronics calibration) and light flasher systems. It is worth noting, though, that some changes in response affect individual tiles only, and would not be discovered by sampling a subset. An example is fiber splice failure.

Finally, it may be necessary to replace the longitudinal mask on occasion, so the capability must exist to repeat the full (every tile) source calibration through the life of the experiment.

These different tasks do not necessarily have to be performed using the same radioactive source, or even the same isotope. This note discusses the choice of isotope best suited to the different tasks and to the different mechanical designs of the barrel and endcap EM compartments.

Selection Criteria

The criteria on which the isotope can be selected include:

- type of radiation (gamma or beta)
- energy spectrum
- lifetime
- specific activity
- purity
- availability

These are discussed below in more detail.

Type of radiation

It is desirable to have a negligible contribution to the calibration signal from betas. One reason is the sensitivity to the material between the source and the scintillator, which may differ from tile to tile. For example, the signal from St90 is attenuated by 2% after 25u (1 mil) of plastic (see Fig. 5).

An even more important reason is that the betas curl up in the detector magnetic field, so that the energy deposited in the tile differs when the field is on from when it is off. It is very desirable that this energy be constant in order that we can measure how the instrinsic response of the scintillator changes with magnetic field. Previous measurements have indicated that the difference between field on and off will be as large as 5% in the barrel and 8% in the endcap[Ref. 1] (Fig. 1). The longitudinal mask---which is measured with the field off---may need to be corrected for this effect. At the very least, the impact can be calculated from the field map and confirmed by measuring a subset of tiles.

Energy Spectrum

In order the beta contribution be negligible, the energy spectrum must be soft enough that the energy is absorbed in the material before the tile. This restriction is much stricter in the endcap EM, where the source is separated from the tile by perhaps 0.2mm of stainless steel, than it is in the barrel, where the separating material is approximately 1mm of lead. (In the barrel EM, the source tubes are imbedded in the lead absorber layer). The actual requirement is that the energy deposited due to betas be much less than that due to gammas. A rule of thumb is that betas with an endpoint of a few hundred kev (kinetic energy) are acceptable in the ECEM, while the barrel limit is at least twice as high.

The energy spectrum of the radiated gammas determines the depth of calorimeter illuminated by the source. Figure 2 is a EGS calculation of the energy deposited in a 4mm scintillator tile by a gamma source as a function of the thickness of lead between the source and the tile. The calculation averages over all emission angles of the gamma and is performed for various gamma energies. This average over all angles results in the apparent increase in the absorption length with depth; ie, the curves are not straight lines but rather flatten out with increasing lead thickness. Note that there is no lead behind the tile. This lead would increase the deposited energy by 10–20%.

In addition to the absolute values shown in Fig. 2, there are two quantities that are especially relevant to the barrel EM. The ratio E1/E0 (the energy deposited after 1mm of lead divided by the energy with no lead) represents the decrease in signal due to burying the source tube. A larger value indicates a smaller source to achieve a specified current. The ratio E5/E1 is the ratio of energy after 5mm lead to energy after 1mm, and indicates the degree to which the illuminated tile (pair of tiles) is separated from the next tile. The equivalent quantity for the endcap EM is the ratio E6/E0. These three quantities are plotted as a function of gamma energy in Fig. 3.

Quality control and longitudinal masking are significantly simplified if only a single tile (or pair of tiles in the barrel) is illuminated, ie, if E5/E1 or E6/E0 are small. For the endcap EM, E6/E0<5% implies Egamma < 430 keV. In the barrel, the situation is more complicated. The equivalent requirement, E5/E1<5% gives Egamma < 280 keV. However, the requirement that there actually be some signal---E1/E0>5%---leaves only the narrow window 190<Egamma<280 keV.

There is still another consideration in the barrel: variations in the source tube location induce variations in the observed signal due to gamma attenuation. Figure 4 shows the impact on a single tile of a 100u shift in the source tube location within the absorber layer, and the impact on the sum of a pair of tiles on either side of the source. As Craig Blocker has previously pointed out, placing the tubes in the lead forces the calibration to be done by tile pairs. The pair sensitivity assumes that after the shift, one tile is located after 0.9mm of lead, while the other is after 1.1mm of lead. It also assumes that the tiles are infinitely large. Clearly, the actual situation is more complex. Nevertheless, for the pair sensitivity to be less than 1% for a 100u shift, the gamma energy must be greater than 250 keV. In other words, the requirement that the source illuminate each tile pair uniformly is nearly inconsistent in the barrel EM with the desire to isolate adjacent layers.

The EGS calculation in Fig. 2 uses ecut=0.52, pcut=0.01 and the Fixtmx option (Estepe=0.003). This option is intended to increase the accuracy of results at low incident energies. In order to check the accuracy, the attenuation of three sources---Sr90, Ru106 and Am241---has been measured as a function of preceding absorber and compared to the EGS calculation. The results are shown in Figures 5--7. St90 is a pure beta source with a relatively high endpoint, and was attenuated with lucite. The Ru106 was attenuated with lead. The signal is due to both gammas (512 keV and 622 keV) and the high energy beta. The beta deposits noticable energy because of x-rays produced by the beta interactions in lead. Finally, the Am241 signal is due to very low energy gammas, 14, 17.6 and 59.5 keV (the alpha does not penetrate even the thinnest layer of aluminum). In this case, after 0.635 cm of aluminum absorber (corresponding to a factor of 8 attenuation), the calculation is approximately 25% low. For Sr90 and Ru106, the agreement is good over a large dynamic range. The conclusion is that EGS can give believable results in source calcuations, with the possible exception of the very lowest energy x-rays.

Half-life

A long isotope half-life would eliminate the need to replace sources and would enable the same source to be used in both test beams and actual operations. However, replacing the source yearly, for example, would not be that great an inconvenience. Given the source current measurement reproducibility of <0.5%, a cross-calibration between different sources of 0.1% accuracy would be achievable without difficulty. A half-life of >8 months is, therefore, sufficient.

Specific Activity

The source strength must be great enough that the induced current is significantly greater than the rms of the PMT dark current and the noise of the monitoring electronics. The available specific activity of the isotope (Ci/mg) limits the achievable strength for a particular source configuration. The minimum requirement has not been investigated in this note.

Availability and Purity

Not all isotopes are available at all times. Even relatively common materials, such as Ru106, can take a year to purchase. Other isotopes are not available in pure forms. As an example, Co57 is typically contaminated with approximately 0.5% Co56, which produces much higher energy gammas (~1 MeV).

Recommendations

Table 1 evaluates a number of common (and not so common) sources on a number of relevant factors. The scores represent personal judgment, in many cases, not a calculation.

Source for QC and masking

The source used to produce the longitudinal mask should have good tile separation, a negligible beta contribution and an adequate tile signal, and should not be overly position sensitive (in the barrel). The halflife is of secondary importance. The choices are similar for both the barrel and endcap EM (and for the hadronic calorimeters), and are summarized in
Table 2.

Table 2. Recommended isotopes for longitudinal masking.

Rank	Source	Comment
1	Ba-133	available in Russia only
2	Rh-101	available in Russia only; position sensitivity and signal size marginal in barrel
3	Sn-113	halflife marginal (0.3 yr)
4	Co-57	not for barrel EM; check purity

Source for Stability Monitoring

The source used to monitor the stability during operation should have a negligible beta contribution and a reasonable halflife and tile signal. The tile separation is desirable, but not necessary. The recommendations are listed in Table 3.

Table 1. Evaluation of various isotopes in terms of halflife; size of beta contribution; degree to which tile layers are isolated; signal size from gammas; and availability. Also listed are the primary beta endpoints and gamma energies. Three stars indicate best applicability to SDC (long lifetime, no beta, good isolation, large signals); two and one stars are less suitable. An "X" indicates that the isotope is not acceptable due to that property. When two rows are present in an evaluation, the top row is for the barrel EM, the bottom row for elsewhere.

Isotope Properties				Isotope Evaluation					
	beta (MeV)	gamma (MeV)	half life (year)	half life	beta contrib	tile isolation	gamma signal	availi-bility	Comment
Na-22	0.545	0.511 1.275	2.6	**	** *	* **	*** ***	?	
Mn-54	---	0.835 +x-rays	0.855	**	*** ***	* *	*** ***	?	
Co-57	---	0.122 0.136	0.745	**	*** ***	*** ***	X **	*	
Co-60	0.316	1.173 1.333	5.271	***	*** **	* *	*** ***	***	
Zn-65	---	1.116	0.67	**	*** ***	* *	*** ***	***	
Ge-68	1.899	0.511 1.077	0.742	**	X X	* **	*** ***	?	
Sr-90	0.546 2.283	---	28.5	***	X X	* *	* *	***	
Rh-101	---	.13, .20 0.325	3.3	***	*** ***	*** ***	* **	*	From Russia; barrel position sensitive
Ru-106	0.039 3.541	0.512 0.622	1.02	**	X X	* *	** **	***	
Sn-113	0.364 0.388	0.392 + x-rays	0.315	*	*** ***	** ***	** **	?	Need material to absorb x-rays
Ba-133	0.045 0.075	0.081 0.356	10.54	***	*** ***	** ***	** **	*	From Russia; need material for betas
Cs-137	0.514 1.176	0.662	30.0	***	*** *	* *	*** ***	***	
Bi-207	0.975 1.047	0.569 1.063	32.2	***	*** *	* *	*** ***	?	
Am-241	---	0.060 + x-rays	432	***	*** ***	*** ***	X X	***	Signal is all x-rays

Table 3. Recommended isotopes for stability monitoring.

Rank	Source	Comment
1	Ba-133	available in Russia only
2	Rh-101	available in Russia only; position sensitivity and signal size marginal in barrel
3	Cs-137	barrel EM only
4	Mn-54	replace source yearly

Discussion of Recommended Isotopes

The recommended isotope, Ba-133, is well suited for both longitudinal masking and stability monitoring, for all parts of the calorimeter. There are no significant beta decays, and the primary photon energies (302 keV and 355 keV) give adequate signals in the tile (approximately 40% of Cs-137 after 1mm of lead). The isolation between tiles is very good in the endcap EM, with the next layer signal being ~2% of the primary layer. The isolation is not as good in the barrel EM (next/primary = 10%) but is significantly better than Cs-137 (next/primary = 30%). The halflife is very good, 10.5 years. The primary problem is that it is produced only in Russia. Isotope Products Inc. has ordered some, and is hoping to receiving it in the next year. Ba-133 is produced by neutron bombardment of Ba-132, and should be available in very high purity. The decay product, Cs-133, is stable.

The second choice, Rh-101, is also available from Russia only. The primary concern with its use is the sensitivity of the barrel EM signal to source location, which simple calculations indicate will be 2% per 100u. This value needs to be experimentally determined. If it is found to be acceptable, Rh-101 provides much better tile isolation than Ba-133: E5/E1 < 1% and E6/E0 < 0.1%. This isolation is achieved at the cost of a signal that is 25 times lower per mCi than Cs-137 in the barrel (but only 3 times lower in the ECEM).

Sn-113 is very short-lived and provides poorer isolation than Ba-133. It may, however, be more readily obtained. Co-57 is suitable only for the endcap because of the low photon energy. Tests are underway to see if the purity improves with time. The short halflife make it less desirable than the first two, in any case.

Cs-137 is a good choice for the barrel EM if tile isolation is not desired. The nonnegligible beta component make it less suitable for the endcap EM and elsewhere.

References

1. J. Mainusch, et al. "Influence of magnetic fields on the response of a uranium scintillator electromagnetic calorimeter", NIM A312 (1992) 451.

Figure Captions

1. Change in response of a scintillator (SCSN-38) uranium calorimeter to 2 and 6 GeV electrons as a function of magnetic field.

2. Energy deposited in a 4mm scintillator tile as a function of the thickness of lead absorber separating the tile from a gamma source (EGS calculation). The different lines correspond to different photon energies.

3. Three ratios relevant to the barrel and endcap EM compartments. E6/E0 is the ratio of the energy after 6mm to the energy with no absorber; E1/E0 is the same ratio for 1mm lead; E5/E1 is ratio of the energy after 5mm to the energy after 1mm.

4. Fractional increase in the energy deposited in a tile after 0.9mm lead relative to 1mm as a function of gamma energy (dashed line) . Solid line is the fractional increase in the sum of energy after 0.9mm plus energy after 1.1mm, relative to 1mm. This quantity is a measurement of the sensitivity of the signal from a pair of tiles to movements of the source.

5. Signal observed in a scintillator tile as a function of the thickness of aluminum absorber between the tile and an Am241 source. Diamonds are data, squares are an EGS calculation.

6. Signal observed in a scintillator tile as a function of the thickness of lucite absorber between the tile and a Sr90 source. Diamonds are data, squares are an EGS calculation.

7. Signal observed in a scintillator tile as a function of the thickness of lead absorber between the tile and a Ru106 source. Diamonds are data, squares are an EGS calculation. The dotdash line is the contribution from beta decays.

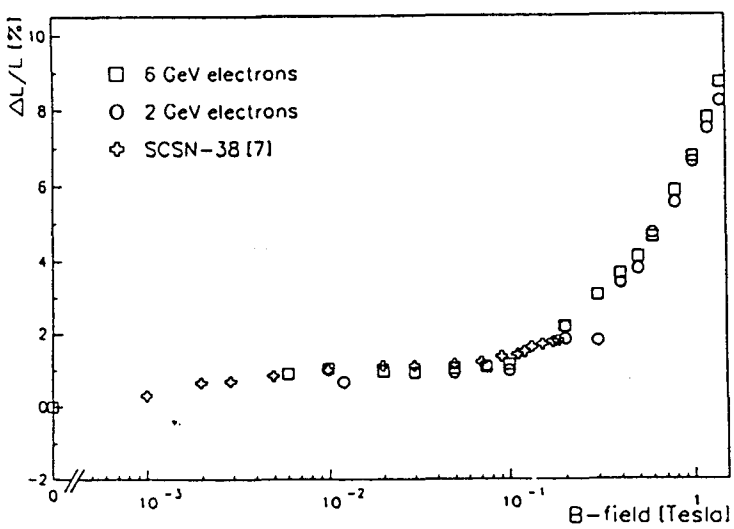

Figure 1

Gamma-Source Attenuation in Lead

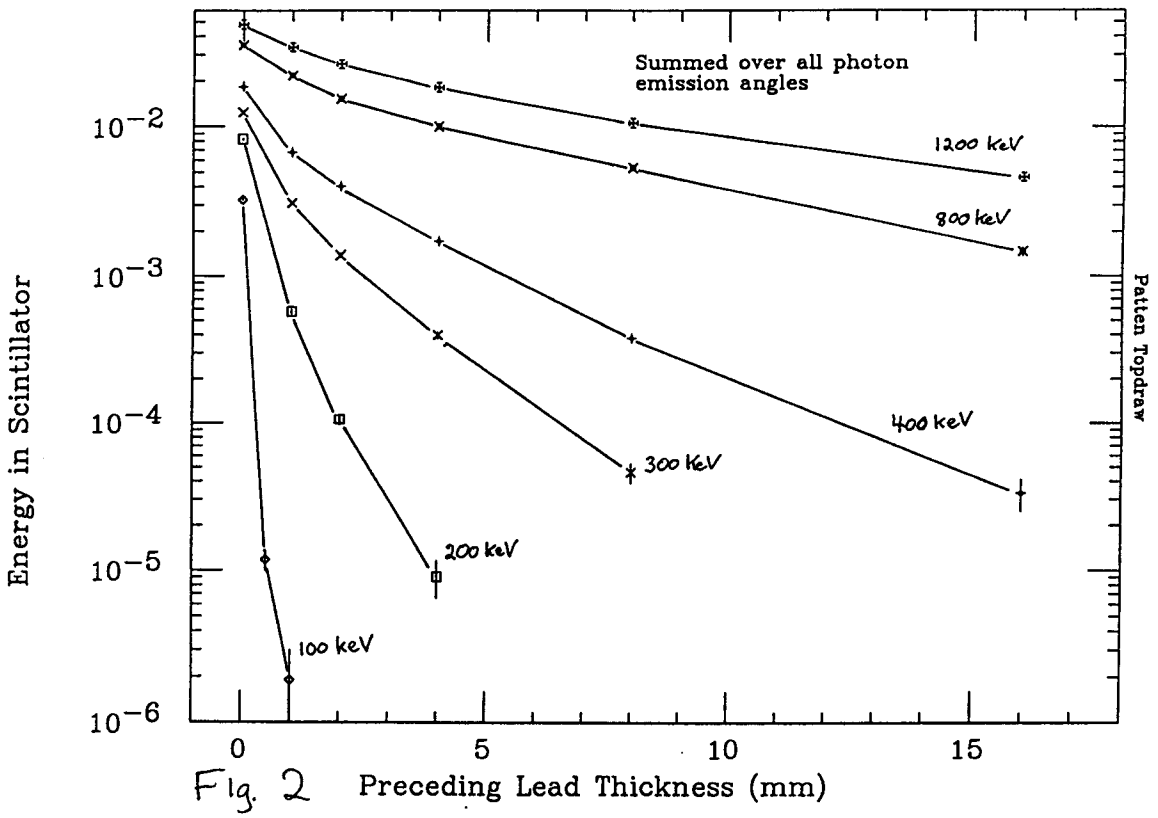

Fig. 2

Signal Ratios vs Photon Energy

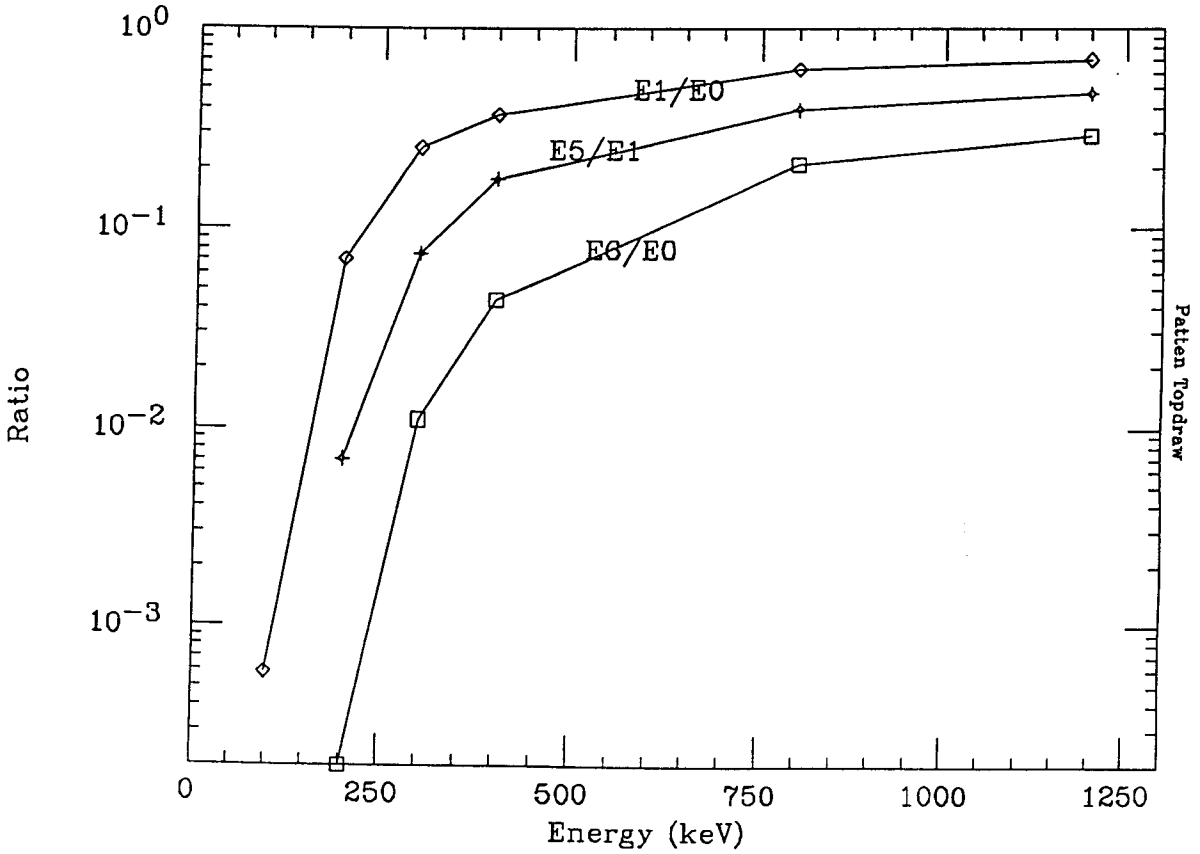

Fig. 3

Sensitivity to 100u Shift in Source Location

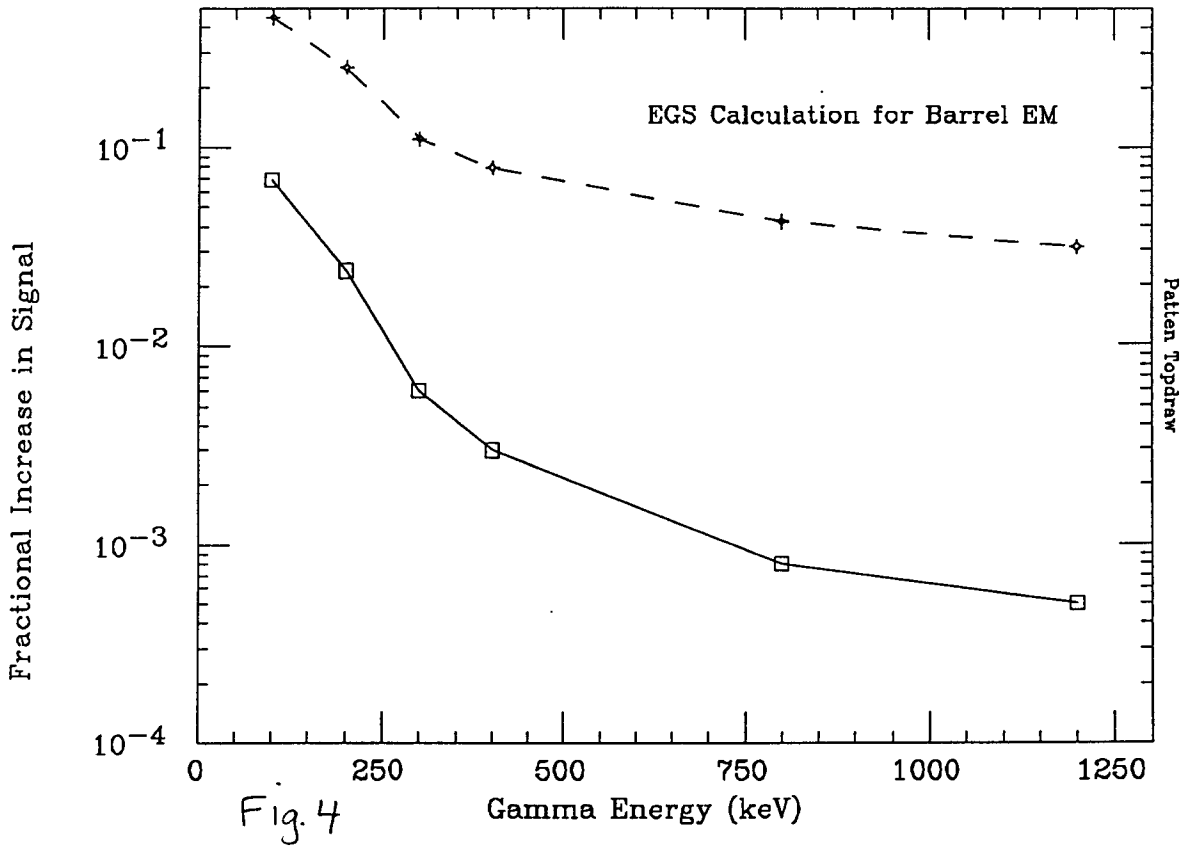

Fig. 4

Am241 Current vs Al Absorber

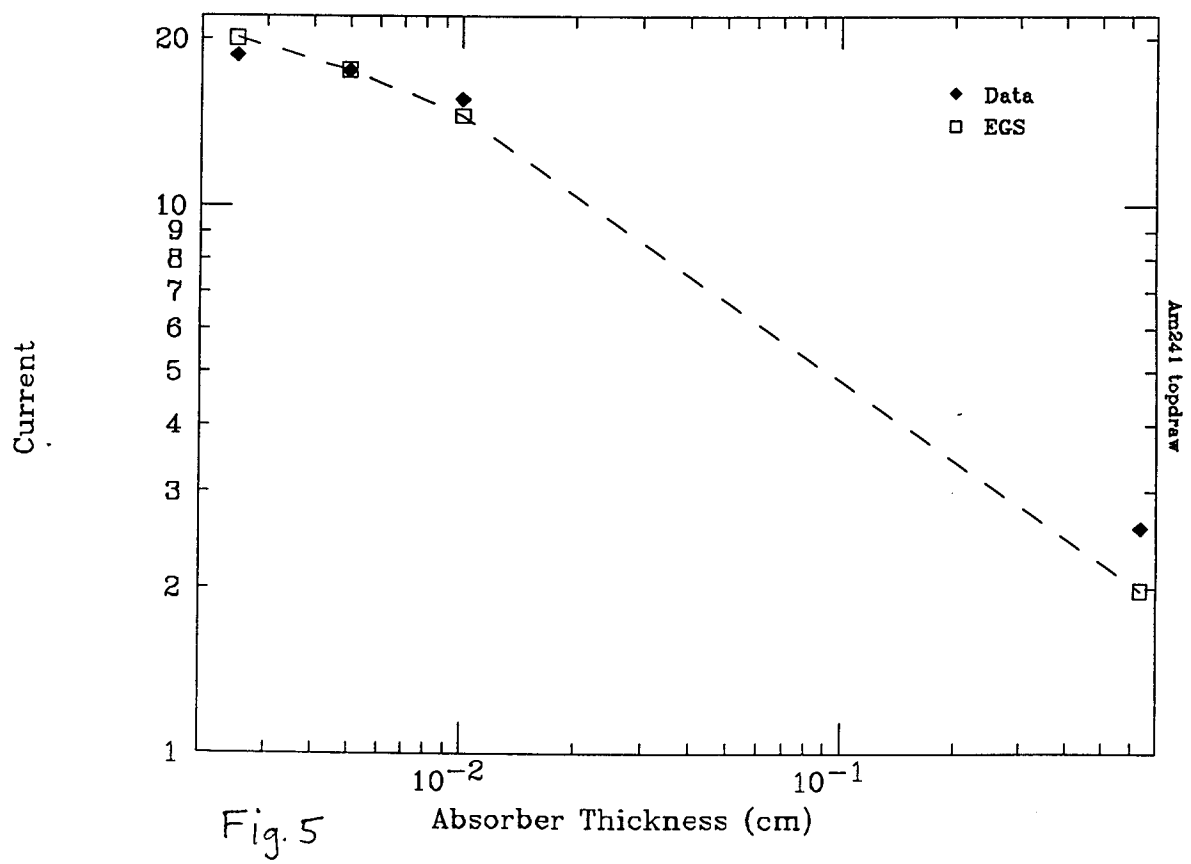

Fig. 5

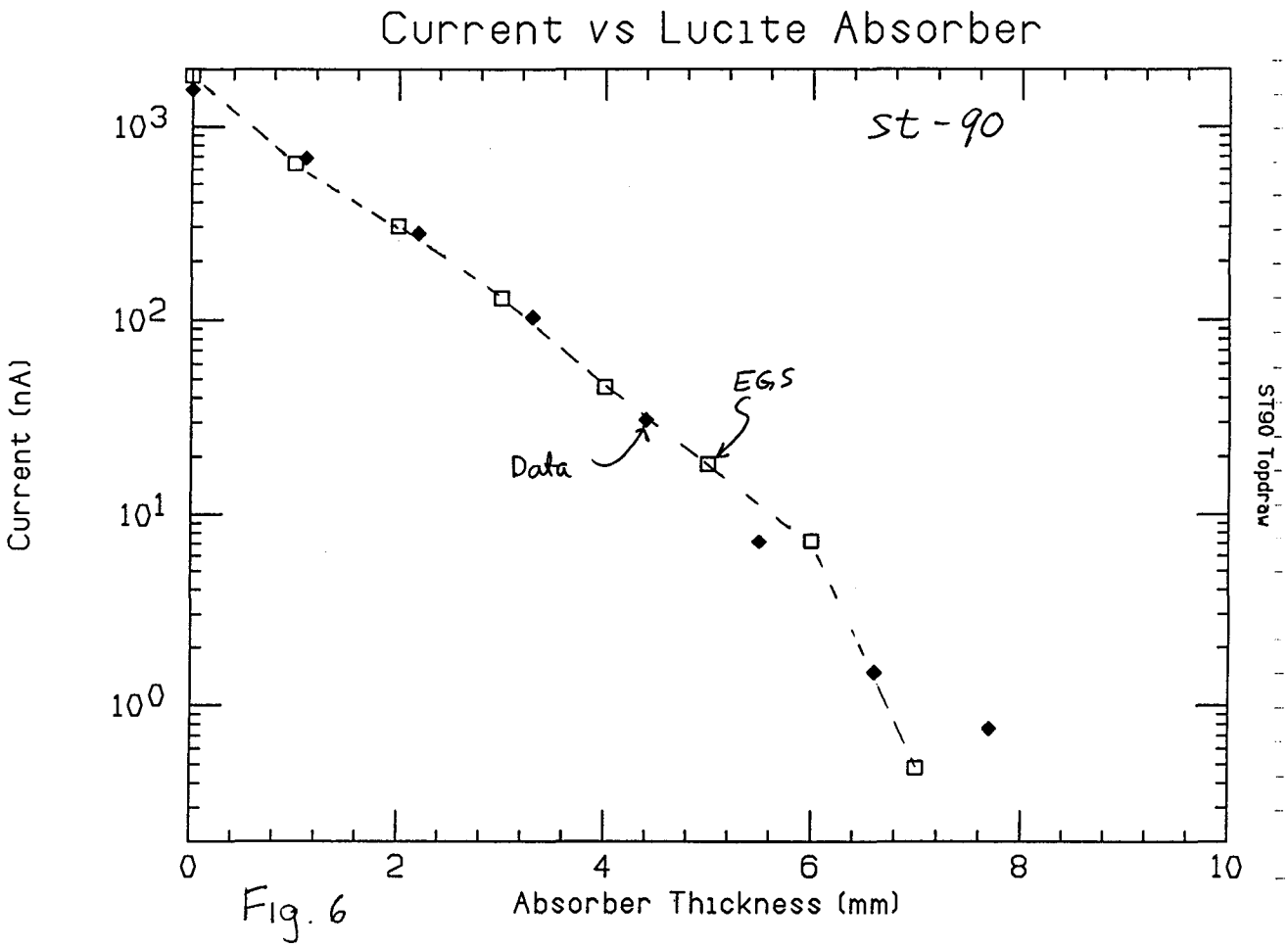
Current vs Lucite Absorber
st-90
EGS
Data
Current (nA)
Absorber Thickness (mm)
ST90 Topdraw

Fig. 6

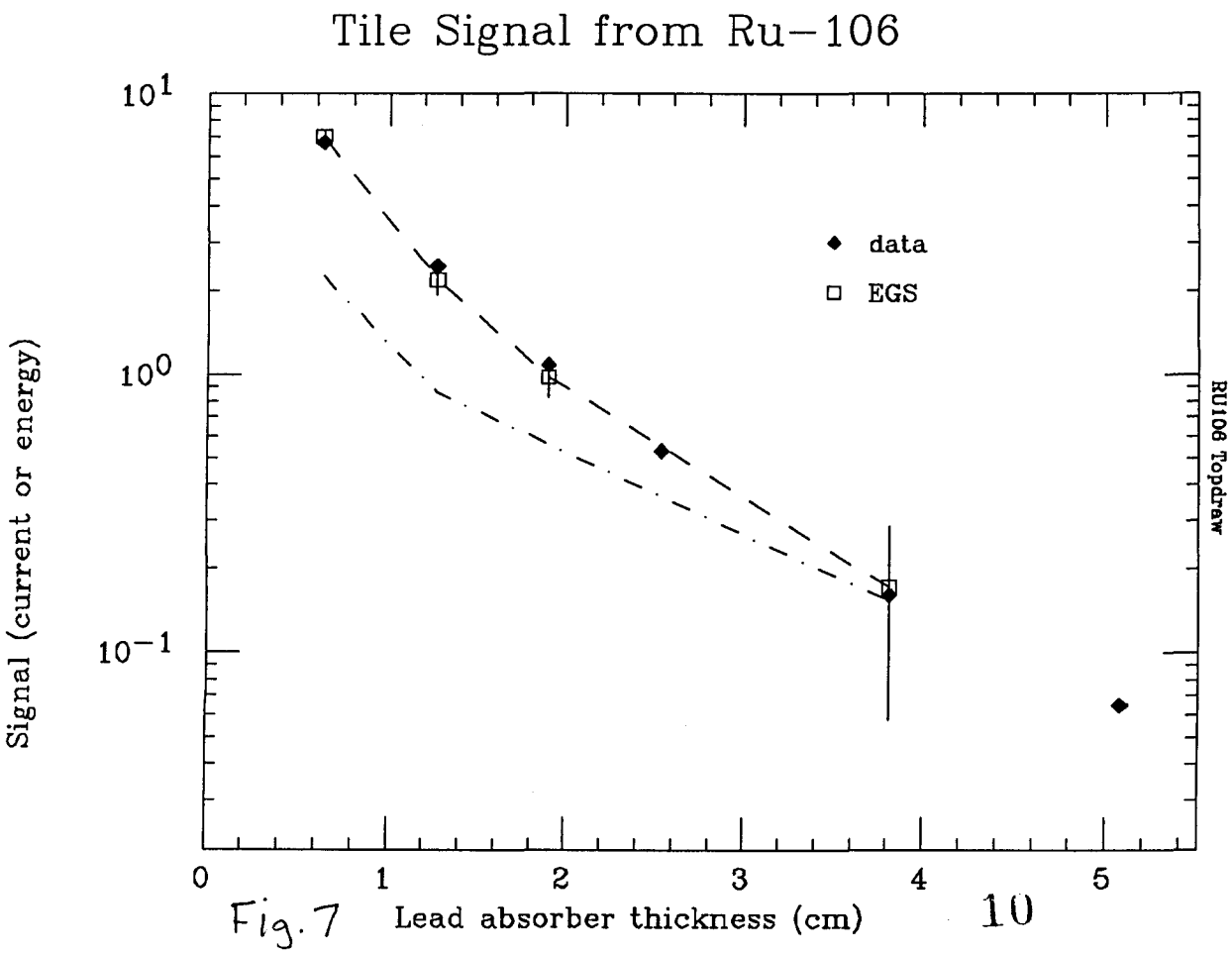
Tile Signal from Ru−106
data
EGS
Signal (current or energy)
Lead absorber thickness (cm)
RU106 Topdraw

Fig. 7