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# EGS4 CALCULATIONS FOR A PEP-II LUMINOSITY MONITOR[⋆†]

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## ABSTRACT

The Asymmetric B-Factory currently being built at SLAC consists of a 9 GeV electron storage ring and a 3 GeV positron storage ring, known as PEP-II, and a large detector called BaBar. Because the commissioning of PEP-II starts approximately one year ahead of the installation of BaBar, it is desirable to have a dedicated system in place beforehand for measuring and optimizing the luminosity of the colliding beams. Accordingly, the EGS4 Code System has been used in the design of a quartz-glass Cherenkov hodoscope that monitors high-energy showers, initiated by photons emanating from radiative-Bhabha interactions at the Interaction Point located 8.5 meters upbeam. In this paper we present the results of a series of EGS4 calculations to determine the spatial resolution of such a detector, as well as to determine if there will be any serious limitations caused by radiation damage.

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# 1. Introduction

The commissioning of the PEP-II facility, approximately one year ahead of the installation of the BaBar detector, has made it desirable to have a dedicated system in place for measuring and optimizing the luminosity of the colliding beams: 9 GeV electrons and 3 GeV positrons. One of the constraints we face is that the detector must reside outside the vacuum chamber. A convenient location has been identified, about 8.5 meters from the Interaction Point (IP), where synchrotron radiation is allowed to impinge on what we will refer to in this paper as the "SR dump"—a portion of the vacuum chamber consisting of a 6°-slanted pair of aluminum plates with water flowing in between for cooling purposes. Figure 1 is a sketch that shows the SR dump and the luminosity monitor, a Pb-shielded hodoscope of quartz-glass Cherenkov detectors.

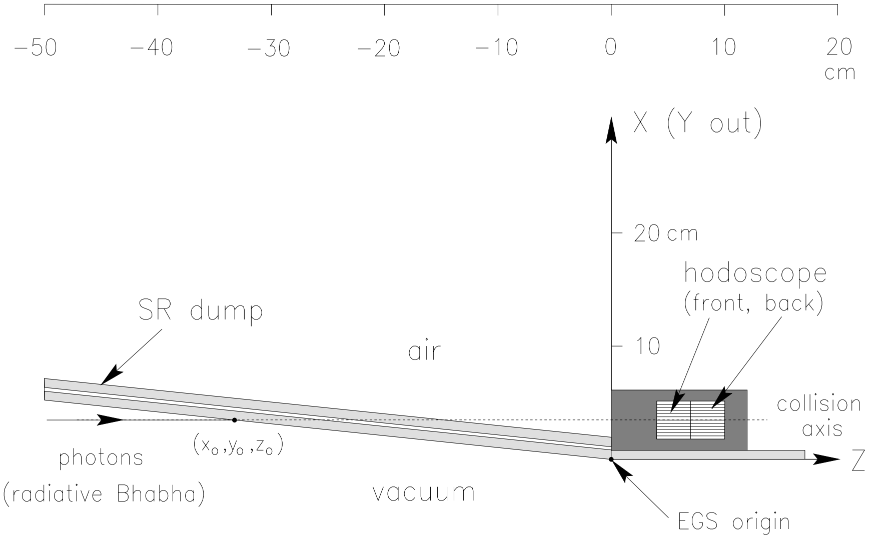

Fig.1 Sketch of the SR dump and luminosity monitor (Pb−shielded, quartz−glass hodoscope).

The main thrust of this design is the detection of electromagnetic showers produced in the SR-dump, and continuing in the Pb shield and quartz glass, initiated by high-energy photons coming from radiative-Bhabha interactions of the $e^+e^-$ beams. More specifically, the <u>collision axis</u> shown in Figure 1 points back to the IP, 8.5 meters away, where a $1/E$ spectrum of photons is produced along the direction of the 3.11 GeV <u>positron</u> beam.

Calculations have been performed using the EGS4 Codes System[1] in order to design a hodoscope system that will give us not only information about the (relative) luminosity, but also some indication of the size of the beam-beam interaction at the IP. In addition, it is important to understand the radiation-damage issue, *i.e.*, the darkening of the quartz glass, and EGS4 provides us with this information as well.

# 2. Details of the EGS4 Simulation

## 2.1 DETECTOR GEOMETRY

To make it easy to modify the elements of the hodoscope, *i.e.*, the number and the dimensions of the quartz glass and the surrounding Pb shield, we started with a general-purpose, rectilinear-coordinate EGS4 User Code, called `ucgetxyz.mortran`*. Figure 1 shows the EGS coordinate system with the rectilinear box, *i.e.*, the luminosity monitor (plus the aluminum support plate), located to the right of the origin. The job of specifying the geometry has been simplified by means of `SUBROUTINE GETXYZ`, and a matching `SUBROUTINE HOWFAR`, whereby data is read in from a file. The instructions for creating this geometry data file are documented within the `GETXYZ` routine itself.

Of course, the geometry to the left of the EGS origin in Figure 1 does not meet the specifications of the standard rectilinear package. That is, modifications had to be made to `HOWFAR` to account for the SR dump. Essentially, the SR dump portion was hard-coded as two 5/16-inch thick Al plates, separated by 1/8-inch of water, with everything slanted at a $6^\circ$ angle as shown in the sketch. Photons enter the geometry from the left side and particles, after transporting through the SR dump, then enter the standard rectilinear geometry defined by the data-input file.

It should be pointed out that we ran all of our calculations using the `autodbl` compiler option, a feature that is available with the IBM/Aix version of UNIX for automatically promoting from single to double precision. The final version of the User Code (called `uclumin3.mortran`) contains other features required by this problem, such as a biasing scheme (described below) for sampling a $1/E$ photon spectrum over the full energy range of interest. A representative example of the data-input file (`uclumin3.data`) is provided in Appendix 1 for the interested reader.

## 2.2 SAMPLING THE RADIATIVE-BHABHA SPECTRUM

A standard technique for determining the luminosity of colliding $e^+e^-$ beams is to measure the Bhabha-interaction rate by means of shower counters placed close to the beam pipe on either side of the IP (*e.g.*, part of the end-cap detector system). In the case of the B Factory at SLAC, the close proximity of machine magnets to the IP beam pipe leaves little room for detectors which can provide the desired rate for luminosity tuning. The luminosity monitor presented in this paper is designed, instead, to take advantage of the high rate of photon production from radiative-Bhabha interactions.

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* `ucgetxyz.mortran` is a SLAC version of the `xyzdos.mortran` code that comes standard with the EGS4 distribution package.

A Monte Carlo code has been written by Kleiss and Burkhardt[2] for calculating the spectrum. Nevertheless, we decided not to use this code, or the results from it, directly within EGS4 because we wanted to avoid additional fluctuations in our final results, caused by yet another Monte Carlo procedure. Instead, we observed that the output from Kleiss's `bbbrem.fortran` code was very well fit with a $1/E$ shape over the entire range of interest, 10 MeV to 3.11 GeV. In addition, in order to account for the high-energy portion of the spectrum in a better way, we elected to sample the spectrum uniformly over the 10 MeV–3.11 GeV energy range and to use $1/E$ as a weighting factor.

An integrated cross section of 352 mb was obtained using `bbbrem.fortran`[3]. Therefore, since all of our calculations have been normalized per incident photon, a multiplying factor of $10^9$ photons/sec, corresponding to a PEP-II design luminosity of $3 \times 10^{33}$ cm$^{-2}$sec$^{-1}$, can be easily applied to obtain event rates. Note, however, that the bunch crossing rate is 238 MHz, and so multiple gammas can occur per pulse. Such coincidences are not considered here.

### 2.3 MATERIAL DATA

The index of refraction for the quartz glass ($n = 1.46$) sets a limit on the energy below which Cherenkov light will not be produced. This turns out to be 0.701 MeV (total energy). Accordingly, we set `ECUT=PCUT=0.7` MeV in all of the EGS4 simulations that we performed. Originally, we used PEGS4 to create media data with `AE=0.521, AP=0.001` and `UE=UP=15000` MeV, and we set `IAPRIM=1` to make the radiative stopping powers compliant with ICRU-37. Later on we switched to PEGS4-created data using `AE=AP=0.7` MeV, after we observed a significant improvement in efficiency without seeing any difference in the results.

### 2.4 SCORING THE CHERENKOV LIGHT

The number of Cherenkov photons radiated by electrons per unit path length (neglecting $\omega$ dependence) can be shown to be given by[†]

$$\frac{dN}{d\ell} = \left(\frac{dN}{d\ell}\right)_0 \left[\frac{1 - 1/\beta^2 n^2}{1 - 1/n^2}\right]$$

where $\beta$ is the particle velocity relative to the speed of light, and $n$ is the index of refraction. The constant term ($dN/d\ell$ when $\beta = 1$) can be estimated from basic principles, but we have elected to use a value of 200 quanta/cm based on experience with quartz glass[‡] .

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[†] *e.g.*, see Eqn. 13.79 of Jackson[4]

[‡] Geometric losses of photons in the hodoscope elements are not included at this stage, since the optical design is not yet fixed.

The way we have implemented the scoring in `uclumin3.mortran` is to keep a running sum of the number of quanta produced in each quartz-glass region, `DeltaN(IRL)`, on an incident photon (event-by-event) basis, and to determine (in `MAIN`) if the sum is greater than a particular threshold (*e.g.*, $> 50$ quanta, $> 100$ quanta, *etc.*). For example, in `SUBROUTINE AUSGAB` we have the code

```
CerLit=TVSTEP*(1.0 - CerCon1/BETA2/E(NP)**2); "No. quanta"
DeltaN(IRL)=DeltaN(IRL) + CerLit; "Event-by-event (region) array"
```

where `CerCon1=PRM**2/(RefIndex**2 - 1.0)` and `RefIndex` is the index of refraction [the other terms should already be familiar to EGS users]. In `MAIN`, after returning from `CALL SHOWER`, we simply compare `200*DeltaN(IRL)` with threshold values and score the weight of the incident particle accordingly[§] .

## 3. Calculation Results

### 3.1 Peak Signal and Spatial Resolution Studies

Calculations were done for a variety of Pb shields and quartz-glass element dimensions. Weighted counts ("hits") were scored into 2D (X-Y) histograms—a different histogram for each threshold. Slices of these histograms (*i.e.*, integrated projections over X or Y) provide information about the peak height and resolution (width) of each distribution. For example, Figure 2 shows the distribution of hits (threshold: $N > 400$ quanta) in the first Z-layer of quartz-glass, shielded on the front face by 4-cm of Pb.

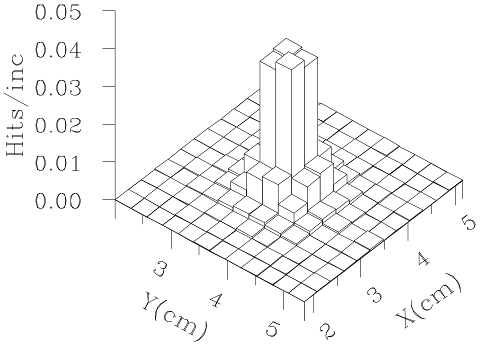

Fig. 2 2D spatial distribution for first layer of quartz glass with 4-cm Pb front shield (threshold: N > 400 quanta).

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[§] Remember that we are performing a biased sampling of the incident energy and `WTinc=1/Einc`.

Figure 3 is a slice along the Y-direction of the 2D histogram in Figure 2. The "hits/inc" are actually the sum of all of the bins along X at each value of Y.

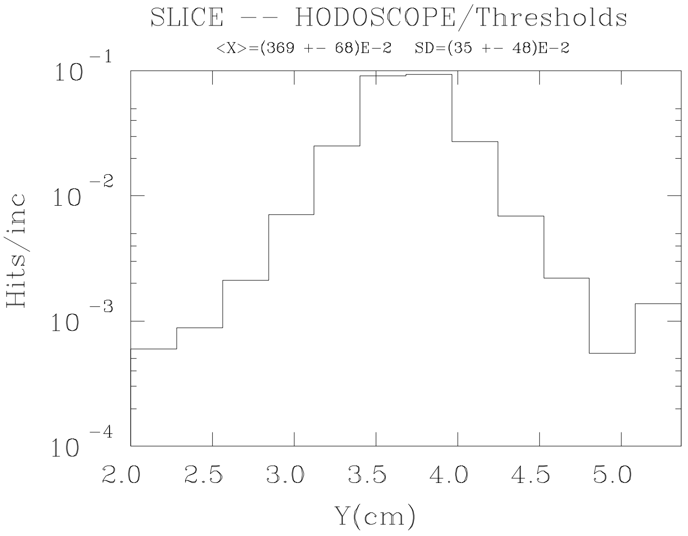


Fig. 3 Y–slice of Figure 2 (threshold: N > 400 quanta).

Figure 4 shows a slice for a 2D histogram having a lower threshold of $N > 10$ quanta (4-cm of Pb still). Note that there are about ten times as many "hits/inc" for $N > 10$ than for $N > 400$ and the resolution is nowhere near as good.

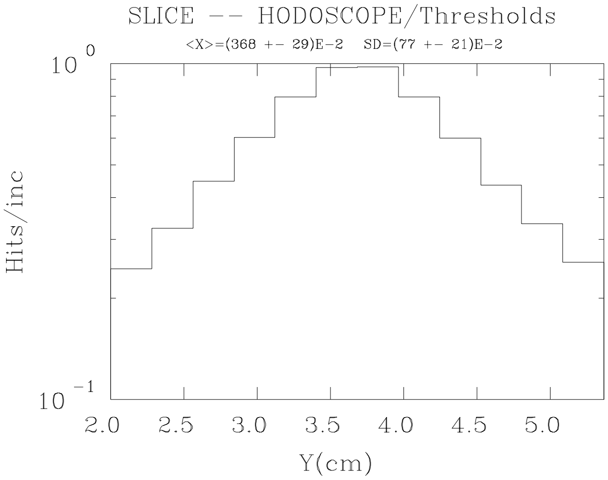


Fig. 4 Y–slice of another 2D histogram (threshold: N > 10 quanta).

Computer runs were made for Pb front thicknesses of 1, 2, 3, 4 and 6 cm and 2D histograms were created for thresholds ranging from 1 to 1000. In Figures 5 and 6 we plot the peak signal and the resolution, respectively, as a function of the threshold. The resolution starts to improve when the threshold is set at about 100, but this is also accompanied by a loss in the peak signal.

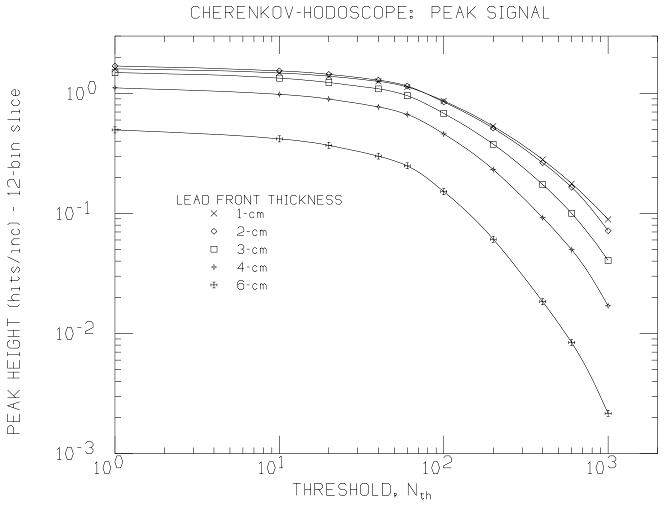


Fig. 5 Peak signal as a function of thresheld for various thicknesses of Pb front shield.

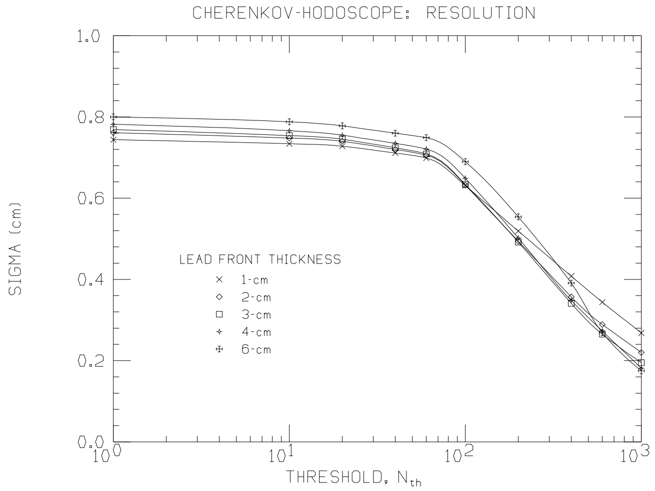


Fig. 6 Resolution as a function of threshold for various thicknesses of Pb front shield.

Nevertheless, as we have stated earlier, there are about $10^9$ incident photons/sec at the PEP-II design luminosity and this loss in peak signal may be acceptable at high intensity. Note, however, that counters on the periphery need to have a meaningful signal if the width is actually to be estimated—and their signals can be orders of magnitude lower.

### 3.2 RADIATION DAMAGE TO QUARTZ GLASS

The absorbed dose (rad/inc) in the quartz glass elements was determined by simply keeping track of the energy deposition. Naturally, the center-most elements sustained the highest dose. If we assume that the glass can withstand a dose of approximately $10^8$ rad, we can estimate the time it takes for the center elements to become too dark to be useful. In Figure 7 we plot the dose rate (rad/sec) as a function of the thickness of the front shield of Pb. The curves are for the hodoscope element immediately behind the front Pb shield (Front) and a second orthogonal hodoscope element behind the first (Back) (see Figure 1). The horizontal lines show how long it will take to reach $10^8$ rad.

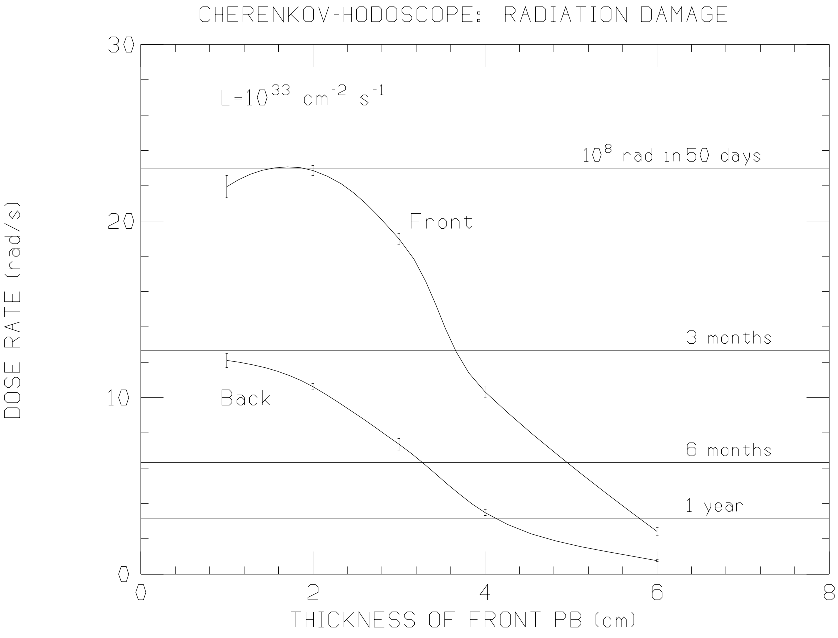


Fig. 7 Dose rate in center quartz–glass elements as a function of the thickness of the front Pb shield.

## 4. Concluding Remarks

In summary, several aspects of the design and performance of the luminosity monitor have been examined by the use of EGS. Estimates of the raw light yield (and its angular distribution and pulse-to-pulse variation, not discussed above in the interest of brevity) have heavily constrained the design parameters of light collection efficiency and photomultiplier gain. For example, it has been established that enough light can be collected into a set of five 8-mm diameter photocathodes, and that the amplification will need to be about $10^6$. The transverse spatial distributions have shown that only by working with the largest pulse heights will the resolution allow the intrinsic gamma beam transverse dimension ($\sigma =$ 3.5 mm) to be measured by a hodoscope. The penalty is that data rates will be reduced by two orders of magnitude. However, the position of the photon beam spot can be measured readily. Finally, the radiation dose rates indicate that the device will be working near its limit. We must either protect it by using a thick lead converter (sustaining a large reduction in signal), or be prepared to replace the quartz as its integrated dose limit is approached.

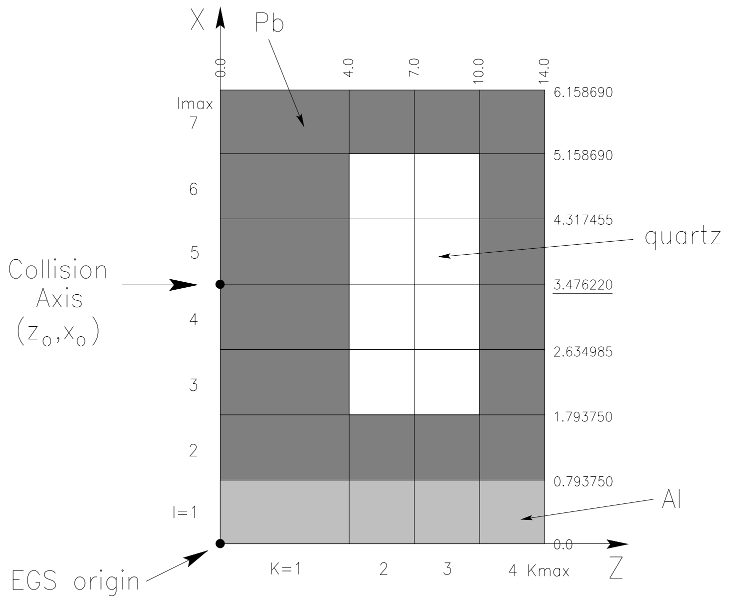
## REFERENCES

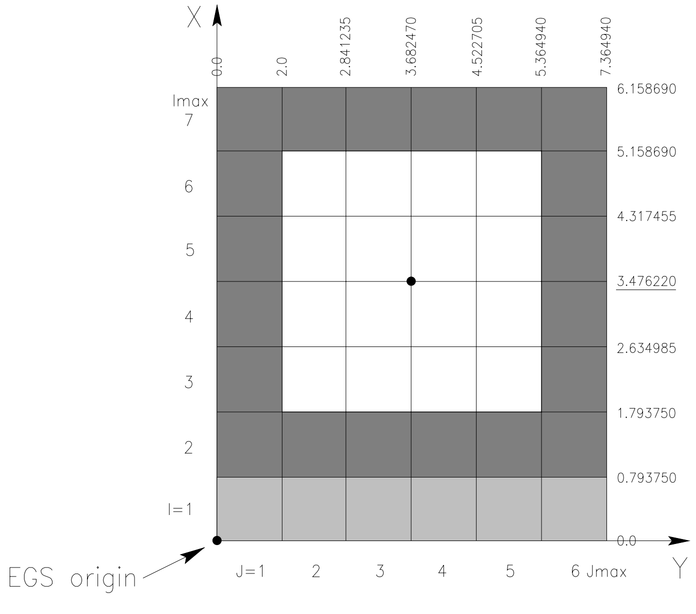
1. W. R. Nelson, H. Hirayama and D. W. O. Rogers, “The EGS4 Code System”, SLAC Report 265 (1985).
2. R. Kleiss and H. Burkhardt, “BBBREM – Monte Carlo Simulation of Radiative Bhabha Scattering in the Very Forward Direction”, Comp. Phys. Comm. 81 (1994) 372.
3. L. P. Keller, private communication (September 1996).
4. J. D. Jackson, Classical Electrodynamics, Second Edition (Wiley and Sons, New York, 1975).

# Appendix 1

Representative example of the geometry data-input file (`uclumin3.data`)

The rectilinear geometry depicted below (not to scale) is for a Pb-shielded 4 × 4 × 2 array of quartz glass ($SiO_2$ with $\rho = 2.32$ g/cm$^3$) sitting on top of a 5/16-inch thick plate of aluminum. Each glass element is 0.8412350 × 0.8412350 × 3.0 cm$^3$. The shield has 1 cm of Pb on the top/bottom ($\Delta X$), 2 cm on the sides ($\Delta Y$), and 4 cm on the front/back ($\Delta Z$). The value for $x_o$ is fixed by the x-location of the collision axis relative to the EGS origin (see Figure 1). The input data corresponding to this geometry is given on the next page.





# Appendix 1

Representative example of the geometry data-input file (`uclumin3.data`) - continued

```
uclumin3.data (comment card)
         5                     NMED (I10)
PB (UCLUMIN)                   MEDIA(J,1) (24A1)
AL (UCLUMIN)                   MEDIA(J,2) (24A1)
WATER (UCLUMIN)                MEDIA(J,3) (24A1)
AIR AT NTP (UCLUMIN)           MEDIA(J,4) (24A1)
QUARTZ GLASS (UCLUMIN)         MEDIA(J,5) (24A1) (must go LAST)
       0.7       0.7           ECUTIN,PCUTIN (MeV) (2F10.0)
         7         6         4 Imax,Jmax,Kmax (3I10)
       0.0 I=1                 XBOUND (cm) (F10.0) - Origin
  0.793750  =2                 AL (5/16" thick)
  1.793750  =3                 PB (1-cm thick)
  2.634985  =4                 GLASS (each 0.841235-cm thick)
  3.476220  =5                 GLASS - FIXED collision axis height
  4.317455  =6                 GLASS   ==========================
  5.158690  =7=Imax            GLASS
  6.158690  =8=Imax+1          PB (1-cm thick)
       0.0 J=1                 YBOUND (cm) (F10.0) - Origin
       2.0  =2                 PB (2-cm thick)
  2.841235  =3                 GLASS (each 0.841235-cm thick)
  3.682470  =4                 GLASS
  4.523705  =5                 GLASS
  5.364940  =6=Jmax            GLASS
  7.364940  =7=Jmax+1          PB (2-cm thick)
       0.0 K=1                 ZBOUND (cm) (F10.0) - Origin
       4.0  =2                 PB (4-cm thick)
       7.0  =3                 GLASS (1st Z-layer, 3-cm long)
      10.0  =4=Kmax            GLASS (2nd Z-layer, 3-cm long)
      14.0  =5=Kmax+1          PB (4-cm thick)
    1    7    1    6    1    4    1       0.0 PB - Set all same to begin with
    1    1    1    6    1    4    2       0.0 AL - Override above
    3    6    2    5    2    3    5       0.0 QUARTZ - Must go LAST
                                              blank card (required EOF)
  3.476220       0.0           XLOWER,XUPPER(cm) (2F10.0) - x0 (collision axis)
  3.682470       0.0           YLOWER,YUPPER(cm) (2F10.0) - y0
       0.0       0.0       1.0 UIN,VIN,WIN (3F10.0)
         1         1           IXX,JXX (2I10)
     10000                     NCASES (I10)
```