Harshaw Scintillation Phosphors

THIRD EDITION
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For beta detection, liquid scintillators and gas filled counters are commonly employed. In some instances, inorganic crystals can be substituted where advantageous. CaF₂(Eu) in particular is an inorganic crystal that has replaced organic crystals (notably anthracene) in most beta counting applications. High Z materials are generally unsuitable for beta counting since their counting efficiency is significantly reduced by excessive scattering of incident beta particles on the surface of the crystal.

Neutrons do not produce ionization directly in scintillation crystals, but can be detected through their interaction with the nuclei of the scintillator. In the case of plastic and liquid scintillators, this occurs through collisions with hydrogen. Neutrons interact with H atoms to produce an alpha and a triton particle which may in turn be detected by the scintillation they produce in LiI(Eu), LiI(Eu) and ILI(Eu) are readily available inorganic crystals useful for neutron counting. For a more complete description of these materials, refer to Chapter II.

### TABLE 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Wavelength of Maximum Emission (nm)</th>
<th>Decay Constant (μs⁻¹)</th>
<th>Scintillation Cutoff Wavelength (nm)</th>
<th>Index of Refraction**</th>
<th>Density (g/cm³)</th>
<th>Hygroscopic</th>
<th>Scintillation Conversion Efficiency (%)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl)</td>
<td>410</td>
<td>23</td>
<td>320</td>
<td>1.85</td>
<td>3.67</td>
<td>Yes</td>
<td>100</td>
</tr>
<tr>
<td>CsI(Na)</td>
<td>435</td>
<td>9</td>
<td>405</td>
<td>1.67</td>
<td>3.19</td>
<td>No</td>
<td>50</td>
</tr>
<tr>
<td>CsI(Tl)</td>
<td>665</td>
<td>1.8</td>
<td>330</td>
<td>1.0</td>
<td>4.51</td>
<td>Yes</td>
<td>55</td>
</tr>
<tr>
<td>LiI(Eu)</td>
<td>470</td>
<td>0.96</td>
<td>450</td>
<td>1.96</td>
<td>3.49</td>
<td>Yes</td>
<td>55</td>
</tr>
<tr>
<td>Plastic1</td>
<td>350-450</td>
<td>Varied</td>
<td>Varied</td>
<td>Varied</td>
<td>1.06</td>
<td>No</td>
<td>55</td>
</tr>
<tr>
<td>Liquid2</td>
<td>350-450</td>
<td>0.002-0.008*</td>
<td>Varied</td>
<td>Varied</td>
<td>0.99</td>
<td>No</td>
<td>55</td>
</tr>
</tbody>
</table>

** At emission maximum
*** Referred to NaI(Tl) with 5-11 photomultiplier response
1 Primarily used for neutron detection
2 Presented for comparison only, Harshaw does not manufacture
3 Dependent upon composition, values given are typical

### FIGURE 1

Emission spectra of NaI(Tl), CsI(Tl) and CsI(Na) compared to the relative spectral sensitivities of 5-11 and bialkali photomultiplier tube types. The emission curves have been normalized to 100 for illustrative purposes. Harshaw Research Laboratory Report.
Table II gives pertinent data for several photomultiplier tube types frequently used in scintillation counting. The stability, gain and spectral sensitivity of these tubes are adequate for NaI(Tl) and most other scintillation crystals described in this book. Photomultiplier gain stability and pulse height resolution are important parameters influencing the performance of a gamma-ray spectrometer. Tube related pulse height resolution depends upon photocathode uniformity, photocathode sensitivity and first dynode secondary emission ratio. Collectively, these parameters largely determine the resolution performance and stability of a scintillation detector. Tube manufacturers' literature should be consulted for complete descriptions of tube types and characteristics.

3. Characteristics of NaI(Tl) Crystals

NaI(Tl) crystals are a widely used material for scintillation counting. NaI(Tl) has a high luminescent efficiency (approximately 15% energy conversion ratio) and is available in single crystal or polycrystalline forms in a wide variety of sizes and geometries. The emission maximum is centered near 410 nm and is well matched to the response of S-11 and bialkali type photomultiplier tubes (refer to Figure 1). NaI(Tl) crystals have a high atomic number, giving them relatively high stopping cross sections. Calculated cross sections are illustrated in Figure 2, showing the total absorption and separate contributions of photoelectric effect, Compton effect and pair production.

3a. Total Counting Efficiency of NaI(Tl)

For a point gamma ray source and a detector shielded from spurious events, the number of events in the observed spectrum will be related to the disintegration rate of the source. Figures 3 and 4 plot the calculated efficiencies of NaI(Tl) crystals as a function of crystal thickness and gamma ray energy for differing source distances.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>CHARACTERISTICS OF REPRESENTATIVE PHOTOMULTIPLIER TUBES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Nominal Diameter</td>
</tr>
<tr>
<td>4016</td>
<td>5/8</td>
</tr>
<tr>
<td>6199</td>
<td>1 1/2</td>
</tr>
<tr>
<td>6342A</td>
<td>2</td>
</tr>
<tr>
<td>9865</td>
<td>2</td>
</tr>
<tr>
<td>4523</td>
<td>2</td>
</tr>
<tr>
<td>50801</td>
<td>2</td>
</tr>
<tr>
<td>6575</td>
<td>2</td>
</tr>
<tr>
<td>4524</td>
<td>2</td>
</tr>
<tr>
<td>75801</td>
<td>2</td>
</tr>
<tr>
<td>9758</td>
<td>2</td>
</tr>
<tr>
<td>6055</td>
<td>2</td>
</tr>
<tr>
<td>4525</td>
<td>6</td>
</tr>
<tr>
<td>12901</td>
<td>6</td>
</tr>
<tr>
<td>4522</td>
<td>6</td>
</tr>
<tr>
<td>MAAVP</td>
<td>5</td>
</tr>
</tbody>
</table>
FIGURE 3

Efficiency is defined as \( E = \frac{N}{N_0} \times 100\% \)
where \( N_0 \) is the total number of gamma rays per second radiated by the source and \( N \) represents the number of interactions within the detector crystal.

From "Calculated Efficiencies of Nal Crystals" by E.A. Wolicki, R. Jastrow and F. Brooks, NRL Report 4833.

FIGURE 4

From "Calculated Efficiencies of Nal Crystals" by E.A. Wolicki, R. Jastrow and F. Brooks, NRL Report 4833.

These efficiencies \( (E) \) are given by \( (E = \frac{N}{N_0} \times 100\%) \) where \( N_0 \) is the total number of gamma rays per second radiated by the source and \( N \) represents the number of interactions within the crystal. Actual efficiency depends upon absorption by the detector housing and the fraction of interactions that are counted by the electronic circuitry (the electronics in this case are assumed to have 100% counting efficiency). The effect of absorption by the detector housing is important at energies below 100keV and is illustrated in Figure 5 for several housing materials.

FIGURE 5

Percent transmission vs. gamma ray energy for various detector housing and entrance window materials. Harshaw Research Laboratory.

FIGURE 6

Calculated Efficiencies of a NaI(Tl) crystal 1 3/4 inches diameter x 2 inches thick. From "Calculated Efficiencies of NaI Crystals" by E.A. Wolicki, R. Jastrow and F. Brooks, NRL Report 4833.

Figure 3 illustrates the effect of varying crystal thickness when the source is in contact with the crystal. Note that efficiency is not a strong function of crystal thickness for this geometry. In contrast, Figure 4 illustrates a rapid change of efficiency with crystal thickness when the source is 15cm distant from the crystal face. The passage of gamma rays in this instance is nearly perpendicular to the crystal and the increase is roughly exponential with thickness.
In many applications, contact between the source and the crystal cannot be attained. In Figures 6 and 7 curves are plotted to show the decrease of counting efficiency as source distance is increased. In applications where the source is contained within a small volume, well type detectors are particularly useful (see Figure 8).

The efficiency of a well detector varies with gamma ray energy and geometry as plotted in Figure 9. The efficiencies for the various well assemblies in this figure were obtained with sample volumes of less than 3 ml. Above this volume, efficiency decreases since the sample approaches the top of the well, and will, with even larger volumes, project beyond the well.

Several parameters of common well detectors for counting $^{60}$Co are compared with solid crystals in Table III. Figure 10 illustrates a well detector spectrum for $^{137}$Cs with the source placed within and outside of the well. $^{137}$Cs emits a 662 keV gamma and a 27.6 keV tellurium K X-ray in coincidence. In some instances, only one or the other of these photons are detected, producing a low energy peak. If both are stopped, the sum peak results. Figure 10 is a composite of two spectra to illustrate the effects of source placement. Both sets of data were compiled with the same Harshaw well detector using equal live time counting.

**FIGURE 7**
From "Calculated Efficiencies of NaI Crystals" by E.A. Wolicki, R. Jastrow and F. Brooks, NRL Report 4833.

**FIGURE 8**
Various Harshaw well-type detectors and through-hole counters.

**FIGURE 9**
Measured photopeak efficiency of various size NaI(Tl) crystals. From "Basic Principles of Scintillation Counting for Medical Investigators" by C.C. Harris, D.P. Hamblin, J.E. Francis, ORNL 2608/ORINS 30.
DETECTION EFFICIENCY FOR $^{57}$Co AS A FUNCTION OF CRYSTAL SIZE AND SOURCE GEOMETRY

<table>
<thead>
<tr>
<th>Crystal Size (in.)</th>
<th>Source Volume (ml)</th>
<th>Volume (ml)</th>
<th>Source Position</th>
<th>Peak Efficiency (counts/sec/\text{MeV})</th>
<th>Total Efficiency (counts/sec/\text{MeV})</th>
<th>Peak Efficiency</th>
<th>Total Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 x 3 well</td>
<td>1.75</td>
<td>1.75</td>
<td>In well</td>
<td>9600</td>
<td>24,150</td>
<td>0.382</td>
<td></td>
</tr>
<tr>
<td>3 x 3 well</td>
<td>4.5</td>
<td>4.5</td>
<td>In well</td>
<td>9000</td>
<td>25,700</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>1½ x 2</td>
<td>4.0</td>
<td>4.0</td>
<td>In well</td>
<td>3200</td>
<td>12,864</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>3 x 3 solid</td>
<td>20</td>
<td>1.3</td>
<td>On top</td>
<td>4600</td>
<td>17,243</td>
<td>0.346</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>250</td>
<td>1.0</td>
<td>On top</td>
<td>9023</td>
<td>9,193</td>
<td>0.320</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>250</td>
<td>1.0</td>
<td>On top</td>
<td>1,851</td>
<td>6,847</td>
<td>0.271</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>1000</td>
<td>0.8</td>
<td>On top</td>
<td>1,681</td>
<td>5,580</td>
<td>0.295</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1000</td>
<td>0.8</td>
<td>On top</td>
<td>1,056</td>
<td>3,570</td>
<td>0.295</td>
<td></td>
</tr>
<tr>
<td>2 x 2 solid</td>
<td>20</td>
<td>1.0</td>
<td>On top</td>
<td>1,831</td>
<td>6,570</td>
<td>0.279</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>250</td>
<td>1.0</td>
<td>On top</td>
<td>1,152</td>
<td>4,417</td>
<td>0.261</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>250</td>
<td>1.0</td>
<td>On top</td>
<td>759</td>
<td>3,132</td>
<td>0.242</td>
<td></td>
</tr>
</tbody>
</table>

TABLE III

FIGURE 10 $^{125}$I spectrum obtained with Harshaw well detector. The effect of source placement is evident in the illustration. Harshaw Research Laboratory Report.

FIGURE 11 Typical Photofraction for various size crystals as a function of energy and source geometry. Harshaw Chemie B.V. Research Laboratory Report.
FIGURE 12
Typical photofractions for various size crystals as a function of energy and source geometry. Harshaw Chemie B.V. Research Laboratory Report.

CRystal Dimensions
DIA. x HGT.
- 8" x 8"
- 9" x 6.5"
- 8" x 4"
- 5" x 5"
- 4" x 4"
- 3" x 3"
- 2" x 2"
- 1" x 1"

FigurE 13
Typical photofractions for various size crystals as a function of energy and source geometry. Harshaw Chemie BV Research Laboratory Report.

CRystal Dimensions
DIA. x HGT.
- 8" x 8"
- 9" x 6.5"
- 8" x 4"
- 5" x 5"
- 4" x 4"
- 3" x 3"
- 2" x 2"
- 1" x 1"
3b. Photopeak Counting Efficiency

In many applications it is desirable to discriminate against background radiation or other spurious events. In these instances, it is necessary to count only full energy or photopeak counts. Photopeak efficiency can be obtained from Figures 3, 4, 6 and 7 by multiplying the values given by the appropriate photofraction (peak-to-total ratio). Crystal diameter, length and the direction of the incident radiation determine the photofraction at a given energy. Figures 11, 12 and 13 give typical photofractions for crystals of various sizes as a function of energy and source geometry.

An example of a photopeak counting efficiency calculation:

<table>
<thead>
<tr>
<th>Detector</th>
<th>NaI(Tl) 2&quot; x 2&quot;</th>
<th>Energy of Source</th>
<th>662keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Distance</td>
<td>10cm from detector face</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Figure 7 the total per cent efficiency is 2%. The photofraction from Figure 12 is 0.60. Thus, E (photopeak) = (2%) x (0.60) = 1.2%. The calculation shows approximately 1% of the counts emitted by the source at a distance of 10cm will be counted in the energy region near the photopeak.

3c. Temperature Response

The relative light output of all scintillators is a function of temperature. The inorganic crystals and the alkali halides in particular exhibit similar response to temperature as illustrated in Figure 14. This effect is significant in a number of applications such as oil well logging, space exploration and environmental surveillance.

3d. POLYSCIN™ NaI(Tl)

In 1972 Harshaw introduced a unique polycrystalline scintillation material called POLYSCIN™ NaI(Tl). The development of this material was the result of new extrusion and forging techniques permitting detector sizes and geometries previously unobtainable with single crystal ingots.*

In contrast to single crystals, POLYSCIN™ NaI(Tl) is composed of many small crystallites ranging in size from less than 1mm to several millimeters. Because these crystallites are in close contact throughout the material, POLYSCIN™ crystals are fully equivalent to single crystals in optical and scintillation performance. Any light scintillating at the crystal boundaries is negligible. The density of POLYSCIN™ crystals is identical to single NaI(Tl) crystals.

Figure 14

Temperature response of NaI(Tl), CsI(Na) and CsI(Tl). Relative light output has been normalized to 100% for illustrative purposes. Harshaw Research Laboratory Report.

<table>
<thead>
<tr>
<th>CRYSTAL TEMPERATURE — DEGREES CENTIGRADE</th>
<th>RELATIVE LIGHT OUTPUT — PER CENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl)</td>
<td></td>
</tr>
<tr>
<td>CsI(Na)</td>
<td></td>
</tr>
<tr>
<td>CsI(Tl)</td>
<td></td>
</tr>
</tbody>
</table>

Under thermal or mechanical shock conditions, single NaI(Tl) crystals will fracture along cleavage planes. In a detector assembly, a small crack may propagate across the entire crystal, interfering with the uniformity of light collection and producing degradation of detector resolution. POLYSCIN™ crystals are more resistant to thermal and mechanical shock. If a crack is produced by these conditions, it is unlikely the fracture will propagate enough to significantly degrade the resolution of the detector.

Under a standard crush test, POLYSCIN™ crystals measuring 1" x 1" supported approximately 600ps without failure. A similar test using single crystals would be critically dependent upon orientation and surface preparation, since small surface fractures are easily propagated under stress.

The availability of POLYSCIN™ NaI(Tl) has released the detector designer from the physical and geometric constraints imposed by the sizes of single crystal ingots. Economies can be realized by fabricating special geometries directly from POLYSCIN™ ingots and eliminating the costly waste of crystal material associated with machining large single crystal ingots.

*As a single crystal ingot is grown very seldom truly single. The ingot will frequently consist of two or more components of differing crystal orientation. The existence of these components cannot be detected within the ingot, but their boundaries may be observed on the surface by employing the appropriate etching or polishing techniques. The boundaries in no way affect the scintillation performance of a crystal.

4. Pulse Height Spectrometry

A basic principle of scintillation counting is that light output is essentially proportional to the energy deposited within a crystal. This feature is particularly important when selecting a crystal for use as a charged particle or gamma ray spectrometer. To be useful as a spectrometer, a scintillation material must exhibit a high probability for complete absorption of the incident radiation. NaI(Tl) crystals are widely used for gamma ray spectrometry. Other inorganic crystals incorporated into spectrometry systems include CsI(Tl), CsI(Na), TlI(BaI₂) and Bi₄Ge₃O₁₂ (for a more complete description of these materials, refer to Chapter II).

In contrast, organic scintillators are primarily dependent upon Compton collision for stopping power and lose a significant portion of the incident energy to scattering.
5. A Spectrometry System

The basic components of a spectrometer include the detector crystal, a photomultiplier tube, a scintillation preamplifier, a main amplifier and a single or multichannel analyzer. Each of these components should exhibit a response proportional to the energy of the incident radiation.

Figure 15 illustrates a spectrum obtained with a selected 3" x 3" NaI(Tl) detector and a multichannel analyzer. The prominent peak represents events in which the full energy of the 662keV gamma ray was deposited within the crystal. Counts in lower channel numbers indicate events in which partial energy escape was produced by Compton scattering.

An important capability of any spectrometer is the ability to distinguish between gamma rays of similar energy. This parameter is termed resolution and is measured by counting the number of channels between the half maximum point in the full energy peak, divided by the channel number of the peak mid-point and multiplying the result by 100%. Typical resolutions for 662keV gamma rays are 7% or better in small NaI(Tl) detectors.

If there were a 100% correlation between the release of a certain amount of energy in a crystal and conversion of that energy into a pulse of specific size, the pulse height resolution would approach zero. This is not the case since several factors contribute to vary the actual size of the pulses produced. First, statistical fluctuations in light production, second, variations in light reflection and third, internal light absorption may all result in differing numbers of photons incident upon the photocathode. These conditions produce pulses with a variation of size dependent upon the site in the crystal where the gamma interactions occurred. Additionally, non-uniformity of the photocathode production, second, variations in light reflection and absorption may contribute to vary the actual size of the pulses depending upon the distribution of light on the photocathode. Finally, the amplification of each pulse will produce some spread in pulse height due to electronic noise, statistical fluctuations in the number of emitted photoelectrons and in the secondary emission process at the dynodes of the photomultiplier tube.

For radiation interactions below 3MeV, the absorption of detected energy usually occurs in a small region of the crystal relative to total volume. Light collection efficiency limits are imposed by crystal geometry and contribute to variations in the light incident upon the photocathode. It is possible to largely compensate for these effects through a patented Harshaw process that suitably alters the surface reflectivity of the crystal. For example, it is possible for crystals measuring 1/16" diameter by 30" length to exhibit an essentially uniform response along their entire length. This in turn permits such crystals to be used as pulse height spectrometers even though the incident radiation may be too diffuse for use.

6. Characteristics of Gamma Ray Spectra

The details of a gamma ray spectrum depend on the energy and intensity of the gamma radiation as well as the composition and geometry of the detector crystal. The following spectra are typical of several common gamma ray emitters and were obtained with Harshaw NaI(Tl) detectors of varying sizes.

Figure 16 is a 137Cs spectrum representative of those used for evaluating the performance of scintillators. The prominent peak is the full energy peak indicating events completely absorbed by the crystal. Compton events in which a scattered gamma ray travels 180° opposite to the incident radiation produces electrons of 47keV in the crystal. These events produce the Compton edge noted in the illustration. Other scattering events at lesser angles produce the characteristic counts to the low energy side of the Compton edge.

The backscatter peak results from Compton scattering into the detector of gamma rays emitted from the source 180° to the detector. The prominent barium K X-ray peak accompanies the beta decay of 137Cs.

Figure 17 illustrates a more complex spectrum resulting from the decay of 22Na. The 511keV peak is produced by the annihilation of a positron emitted by the isotope and an electron in the source material. This peak is characteristic of many positron emitters. Note the similarity in the Compton and backscatter peaks to those illustrated in Figure 16.

The decay scheme of 20Na also produces a 1223keV gamma. This gamma is emitted at near coincidence with the positron which annihilates to produce a pair of 511keV gammas. Often, these two gamma events will be detected simultaneously within the crystal creating the Sum Peak noted at 1734keV.

Figure 18 illustrates the complex spectrum observed from 22Na in equilibrium with its daughters. A prominent feature of this spectrum is the closely spaced pair of peaks at 511keV and 583keV. The 261kev peak is the highest naturally occurring gamma. Figure 19 shows a 6keV spectrum for 55Fe. A Harshaw Type SHG assembly was used to obtain the data. This type detector incorporates a selected photomultiplier tube and a thin, cleaved NaI(Tl) crystal. The use of thinly cleaved crystals is particularly desirable for good detector resolution at energies near 10keV and lower. Resolution is dominated by the statistics of the number of photoelectrons emitted at the photocathode (in this case approximately five photoelectrons per detected X-ray).
FIGURE 17

$^{22}$Na spectrum obtained with Harshaw Type 12812 Nal(Tl) detector using background subtraction. Harshaw Research Laboratory Report.

FIGURE 18

Spectrum observed from $^{228}$Th and daughters. A Harshaw Type 12812 Nal(Tl) detector was employed for a two minute counting period with background subtraction. Harshaw Research Laboratory Report.

FIGURE 19

A low energy spectrum obtained with a Harshaw Type 5HG Nal(Tl) detector (broad beam). Thinly cleaved Nal(Tl) crystals are used in this type detector to achieve good resolution in applications near 10keV and lower. Harshaw Research Laboratory Report.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>&quot;Luminescent Materials for Scintillation Counters&quot; by G. F. J. Garlick in Progress in Nuclear Physics Vol. 2 Academic Press (1952)</td>
</tr>
<tr>
<td>7</td>
<td>&quot;The Scintillation Counter&quot; by G. A. Morton in Advances in Electronics Vol. 4 Academic Press (1952)</td>
</tr>
<tr>
<td>11</td>
<td>&quot;Applied Gamma Ray Spectrometry&quot; by C. E. Crouthamel Pergamon Press (1960)</td>
</tr>
<tr>
<td>14</td>
<td>&quot;Nuclear Radiation Detectors&quot; by J. Sharpe. Methuen &amp; Co. Ltd. (1964)</td>
</tr>
</tbody>
</table>

In addition the proceedings of various symposia have illustrated more specific applications that may be of use to the reader. These include:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>&quot;Fifth Scintillation Counter Symposium&quot; IRE Transactions on Nuclear Science, Vol. NS-3 No. 4 (1956)</td>
</tr>
<tr>
<td>19</td>
<td>&quot;Sixth Scintillation Counter Symposium&quot; IRE Transactions on Nuclear Science, Vol. NS-5 No. 3 (1958)</td>
</tr>
<tr>
<td>20</td>
<td>&quot;Seventh Scintillation Counter Symposium&quot; IRE Transactions on Nuclear Science, Vol. NS-7 No. 203 (June-September 1960)</td>
</tr>
<tr>
<td>21</td>
<td>Proceedings of Total Absorption Gamma Ray Spectrometry Symposium TID 7594 Gatlinburg, Tennessee May 1960</td>
</tr>
</tbody>
</table>
HARSHAW MOUNTED SCINTILLATION PHOSPHORS

12. STANDARD LINE Assemblies

Harshaw STANDARD LINE detector assemblies consist of right circular cylindrical crystals that have been machined, surfaced, and mounted in precision housings. These assemblies are readily coupled to a wide variety of photomultiplier tube types and offer distinct advantages in versatility and economy. Each STANDARD LINE crystal housing is normally fabricated from aluminum or low background stainless steel and is provided with a hermetically sealed optical window of quartz, Vycor, Pyrex or glass. Crystal housings can also be fabricated from a variety of other alloy materials including OFHC copper and cold-rolled steel upon special request.

Type D assemblies are the basic STANDARD LINE detector. Temporary mounting of these units to photomultiplier tubes can be accomplished using optical coupling compounds and black tape as a light seal. More permanent mounting techniques incorporate epoxy flanges that couple directly to bolt-down magnetic shields. Type A assemblies resemble D style detectors but are fabricated with spun flanges. This type construction permits the use of slip-on adapter rings that couple to bolt-down shields, making the entire assembly fully demountable.

Type AW Top Well detector assemblies permit high counting efficiencies with small volume samples. These units are also fabricated with spun flanges for use with bolt-down shields. Type F well assemblies are manufactured with "lip-and-groove" flanges to facilitate the addition of a rubber "O-ring" between the crystal housing and the shield mounting hardware. The ring protects the spun aluminum housing from damage that may result from over-tightening the shield mounting hardware. These detectors utilize a unique .004" sheet reflector around the well to minimize crystal-to-housing dimensions and gamma ray absorption.

Type AF (through-side-hole) detectors are right circular cylindrical crystals with holes machined perpendicular to the crystal axis. These units are widely used for small volume samples and in flow studies.

Type H assemblies are offered with beryllium or aluminum entrance windows for low energy applications. The crystals used in these detectors are either thinly cleaved or machined and polished, depending upon application requirements. The cleaved crystals are preferred for applications in the soft X-ray region below 10keV since the X-rays are absorbed in the surface layer of the crystal.

Type HG assemblies resemble H style detectors but are fabricated with one-piece spun aluminum housings. These units can be adapted to a wide range of crystal sizes up to three inches. Sheet reflector material is used exclusively in these assemblies to minimize the dimensions between the crystal and the housing and reduce gamma ray absorption.

Type PF and PA assemblies are ruggedized for applications where mechanical shock, large thermal gradients or wide temperature extremes may be encountered. Harshaw guarantees Type PF detectors to withstand temperatures between -50°C and +150°C and 50g's shock. These assemblies are widely used in well logging applications and feature one-piece stainless steel housings. PA assemblies are fabricated with one-piece spun aluminum housings and are widely used as medical probes and in environmental applications. Type PA detectors are guaranteed to operate per specifications in a temperature range of -21°C to +65°C.

Each STANDARD LINE detector assembly carries a two-year warranty against detector failure due to faulty construction, materials or hermetic seals used in the crystal assembly.

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**Type D — Standard Small Crystal Assembly**

Intended Application:
General laboratory research, medical and industrial research.

Crystal Size Range:
- DIAMETER — 0.25" to 5" in increments of 0.25"
- HEIGHT — 0.5" to 5" in increments of 0.25"

A. 0.25" glass — quartz available on special order
B. .032" Type 1100 aluminum
C. Packed Al₂O₃ approximately 0.04" thick

D. — Crystal Diameter
H. — Crystal Height

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**Type A — Low Mass Crystal Assembly**

Intended Application:
High gamma energy or total spectrometry — also recommended for low level counting.

A. 0.25" glass (quartz available upon request)
B. Packed Al₂O₃ approximately 0.04" thick
C. .032" Type 1100 aluminum
D. HR-15 sheet reflector

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**Type AW — Intermediate Size Well Crystal Assembly — 3" Dia.**

Intended Application:
High gamma counting efficiency for small volume solid or liquid samples.

G. 0.25" glass — quartz available upon request
J. Packed Al₂O₃ approximately 0.04" thick
K. .032" Type 1100 aluminum
D. HR-15 sheet reflector
E. .032" aluminum

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**Standard Well Sizes**

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<thead>
<tr>
<th>Standard</th>
<th>Well Dimensions</th>
<th>Wall Dimensions</th>
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<td></td>
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<tr>
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*Also available in additional sizes up to 5" dia., with special wall dimensions upon request.