

Scintillation Detectors

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Scintillation Detectors. A module developed for the International Atomic Energy Agency as part of a training course for the maintenance of Nuclear Electronic Systems.

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A scintillation detector starts with a scintillator, a material that will produce a flash of light when struck by nuclear radiation. The scintillator is usually attached to a photomultiplier tube. The photomultiplier tube is a vacuum tube, flat on one end. The inside of the flat portion of the tube is coated with a photocathode material. This is a material with a low work function, such that when light from the scintillator strikes the photocathode, electrons are emitted. The electrons are then collected into a charge multiplier region in the photomultiplier tube. Here the charge is multiplied or amplified producing output pulse of charge that is proportional to the number of electrons being emitted from the photocathode. This pulse is also then proportional to the amount of light produced in the scintillator, which is proportional to the amount of energy deposited by the radiation.

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Scintillators are frequently connected to the photomultiplier tube using a device called a light pipe.

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Light pipes have three general functions. The first is to match geometries as shown in the next slide.

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In this case, the scintillator is a thin slab of material and is used to detect the presence of a beam of charged particles, in this case a beam of beta particles. The particles pass through the detector depositing only a small portion of their energy. The light from the detector exits through the edge and passes through the light pipe into the photomultiplier tube.

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A second function of light pipes is to separate the photomultiplier tube from the radiation environment. For instance, the photomultiplier tube is very, very sensitive to magnetic fields. If it is required that the scintillation detector be placed in a magnetic field, then a light pipe is frequently used to guide the light away from the magnetic field to the photomultiplier tube. A third function is to improve resolution.

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The sensitivity of the photocathode surface varies greatly across the face of the photomultiplier tube as shown in this slide,. The portion near the center of the photocathode may be considered 100% efficient while regions in the outer areas of photomultiplier tube may be as low 20% efficient. This means that some regions in the outer edges of the photomultiplier tube would only produce one-fifth of the charge for the same amount of light striking the photomultiplier tube.

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If the scintillation crystal is attached directly to the photomultiplier tube, the light from radiation interacting close to the interface would interact only with a small region of the photocathode. Depending on whether the light interacted with the outer region or central portion of the photocathode, one could get a large variation in the amount of charge for a given amount of energy deposited in the scintillation crystal. On the other hand, if the scintillation crystal is separated from the photomultiplier tube, then if the radiation strikes near the end of the scintillation crystal, the light is averaged over the whole area of the photocathode surface giving a uniform or consistent amount of charge emitted by the photocathode.

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An example of the improvement in resolution that can be achieved by using a light pipe to connect a crystal to the phototube are shown on this slide. Here the relative resolution of detector is shown as a function of the thickness of the light pipe. In this case, a 10 cm diameter scintillation crystal is connected to a 12 ½ cm diameter photomultiplier tube. One can see that for this detector system, the resolution for Co-60 is greatly improved with a light pipe that has a thickness of about 2.5 centimeters.

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Scintillation Detector Systems. Common systems for using a scintillation detector are shown on this slide. First, in order to operate, the scintillation detector requires a high voltage. The voltage depends on the type of photomultiplier tube that is used in the system and may vary from about 1,000 volts to about 3,000 volts. The scintillation detector actually requires a number of different voltages. Therefore, the high voltage is usually fed through a voltage divider into the scintillation detector with voltages for each of the dynodes, the focusing grid, and the anode taken from different points of the voltage divider.

The signal from the scintillation detector is then fed into a preamplifier. Although these two units may be separated, they are frequently combined into one module. The signal from the preamplifier is then fed to a main amplifier where it is amplified and finally sent to a pulse analyzing system.

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Properties of Scintillators.

The first function of the scintillator is to convert energy from the radiation to the light. The maximum sensitivity of most photomultiplier tubes occurs when the wavelength of the light spectrum peaks around 440 nm. This is in the range of blue to ultraviolet light in the visible light spectrum. The second property of scintillators is that they must be transparent to light.

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Scintillators can be divided into four main classes.

The first are the inorganic scintillators exemplified by thallium activated sodium iodide. That is sodium iodide with a small amount of thallium added. Other examples of inorganic scintillators might be thallium activated cesium iodide or lithium iodide. Another type of inorganic scintillator is BGO or bismuth germanate and a fifth might be zinc sulfide activated with silver. There are other inorganic scintillators besides these five. The first three listed here sodium iodide, cesium iodide, and lithium iodide are all single crystals, which limits their size of the crystals and makes them expensive. They also are all hygroscopic. This means that they will readily absorb moisture from the air. Therefore, they must be hermetically sealed in order to protect the crystals. If they absorb moisture their scintillation properties change and they become ineffective as scintillators. This condition can be observed because the crystals will change color.

A second class of scintillators would be the organics. Two examples of organic scintillators are anthracene and stilbene. These are low Z materials which means they would be good for detecting charged particles. The problem with these materials is that they are not single crystals, but are actually made up of a multitude of smaller crystals and the light reflects at the planes between the crystals. Therefore, they are limited in their transparency properties and the ability for light to escape the crystal. The maximum useful thickness of these detectors is about one or two centimeters. In addition, anthracene is a carcinogenic material.

A third class of scintillator are the plastics. This type of scintillator might be exemplified by the use of polystyrene with some type of material added to activate it. The additive might be something like tetraphenylbutadiene. Different combinations of materials will give the scintillator different properties. Sizes of plastic scintillators range from a few cubic centimeters to meters.

A fourth class of scintillator would be the liquid scintillator. Historically, the liquid has been toluene plus some material such as PBO or PBD or POPOP added as an activator. However because of the toxic nature of toluene it has been supplemented in more recent years with mineral oil based scintillators. Other materials, including water have been used as scintillators in large detectors used

in high energy physics experiments. In the laboratory, the size of the liquid scintillators are usually in the range of 10 or 20 ml to a few liters.

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This slide shows some of the thousands of photomultiplier tubes used in to detect light from 50,000 tons of water used as a liquid scintillator in system to detect neutrinos from the sun.

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An example of how the scintillation process works in an activated inorganic scintillator such as sodium iodide is shown here. In a single crystal, the electrons are all located in very well defined energy levels as shown here in what is known as a Fermi energy level diagram where the energy of the electrons is shown as the vertical scale. The last electrons in the atoms are all in the valence shell. Then there is a forbidden gap where there are no levels. And finally there will be a conduction band. If the electrons moved into the conduction band, they are free to move around the crystal. Radiation entering the crystal will excite an electron and raise it from the valence band into the conduction band. Nature, however, does not like to be in the excited level, so the electron moves around the conduction band until it reaches the bottom of the level and then de-excites by dropping back down into the valence band. When the electron drops back to valence band, it will emit a light photon. However, for most crystals this light would be too energetic. That is, the wavelength would be too short.

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Therefore, in order to increase wavelength of the photon, a material is added that will introduce extra energy levels in the forbidden gap. In the case of sodium iodide the material would be a small amount of thallium. Now when the electron de-excites, it drops to the energy level in the forbidden gap and then down to the valence band. This means that the photons are lower in energy or the wavelengths are longer moving them into the desirable range around 440 nm.

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The importance of having a proper spectral response from the scintillator is shown in this slide. Here, the response of two typical photomultiplier tubes, with a bialkali photocathode and an S-11 photocathode are shown. It should be pointed out that the responses here have been normalized to 10 units. They are not typical of the actual sensitivity of the photomultiplier tubes. The light output of typical thallium activated sodium iodide and sodium activated cesium iodide scintillators are also plotted on the diagram and one can see that they peak at about 430-440 nm, which matches well with the response of the photomultiplier tubes. On the other hand, if one takes a look at thallium activated cesium iodide, one finds that it peaks at around 550 nm, well outside the range of maximum sensitivity of the photomultiplier tubes.

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Other properties to consider when selecting a scintillator are first the conversion efficiency, that is how much energy must be deposited in the detector to produce one usable light photon. For thallium activated sodium iodide, this is about 13%. In other words, for every 26 eV of energy deposited in the scintillator, one usable light photon will be produced. Anthracene is about 5 % efficient, plastic is about 2%, and liquid scintillators that can be simply considered as a liquid plastic are also about 2%. BGO is about 3% efficient.

Another factor to consider is the density of the scintillator. This becomes important because one wants a high density for stopping and detecting gamma rays or high energy photons. On the other hand, if one wants to detect electrons, one wants a low density scintillator. High density scintillators mean that they have high z nuclei. Charged particles interacting with high z nuclei may back scatter out of the detector. One wants the electrons to scatter in a forward direction. Therefore one wants a low z material.

The final property to consider when selecting a scintillator is the mean lifetime of the conversion process. Remember that the radiation is exciting atoms. The electrons decay back down to the low energy state with a mean lifetime much like the radioactive decay of nuclei. If the mean lifetime is too long, the light is emitted over a long period of time and this will result in a very slow rise time pulse. Therefore one wants the mean lifetime to be on the order of microseconds or less. Usually the shorter the lifetime the better.

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Properties of a number of scintillators are given here. First consider the total number of photons per MeV of energy deposited in the scintillator. This is the conversion efficiency. For thallium activated sodium iodide, one sees that about 38,000 photons are produced for each MeV of energy deposited in the detector. Thallium activated cesium iodide is even higher; almost twice as high. BGO produces only 8,200 photons per MeV.

The second property to consider is the wavelength of the light. That is whether it will be a spectral match with the photocathode. Here one sees that sodium iodide has a peak at 415 nm, whereas cesium iodide has a peak at 540 nm.

The third factor one wants to consider is the specific gravity or the density of the material. One finds that sodium iodide has a specific gravity of 3.67. BGO is much better 7.13, which means that it would be much better for stopping photons.

A fourth factor is the decay constant or the mean lifetime in microseconds. One sees that thallium activated sodium iodide has a decay constant of $0.23 \mu\text{s}$. This will produce a pulse with about a quarter of a microsecond rise time. On the other hand, if one takes a look at cesium iodide one finds that the decay constant

is about 1 microsecond resulting in about a 4 microsecond rise time in the output pulses.

Finally, if one looks at the relative pulse heights with the bi-alkali photomultiplier tube, comparing to the pulse heights to thallium sodium iodide normalized to one, one finds that thallium activated cesium iodide is 0.49 primarily because of the mismatch between the spectrum of the light output and sensitivity of the photocathode.

If one looks at cesium iodide again, one finds that it has many good properties such as high specific density and high conversion efficiency, however the spectral match causes it to produce a relatively low pulse height with a typical photomultiplier tubes.

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Photomultiplier Tubes.

Photomultiplier tubes consist of a cylindrical vacuum tube with a photocathode on the inside. Light entering through the end hits the photocathode producing a pulse of charge. This process is shown on the next slide.

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One end of the photomultiplier tube is flat to provide a better surface for coupling to the scintillator or light pipe. On the inside of the flat end is the photocathode. When light hits the photocathode, electrons are ejected.

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The photocathode consists of material with low work functions, such as antimony, potassium and cesium, or sodium and potassium. Low work functions mean that the outer electrons of the atom are bound with very low energies so it is very easy for low energy light photons to knock an electron out of the atom. The sensitivity of these materials peaks at about 440 +/- 40 nm. A typical S-11 response is about 10% efficient. This means that for every 10 light photons hitting the photocathode, about 1 electron will be ejected. The newer bi-alkali photomultiplier tubes have about 16% efficiency or 1 photoelectron for about every 6 photons hitting the photocathode.

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When the electron is ejected from the photocathode it first sees a focusing grid. The focusing grid is at a potential of about 100 volts positive with respect to the photocathode surface. The electrons are accelerated toward the focusing grid and pass through it to a special electrode called a dynode, which is about 100 volts positive with respect with the focusing grid. Thus the electrons that strike the dynode have gained an energy of about 200 electron volts of energy. When the electrons strike the dynode, which has a special low work function surface, a number of electrons will be ejected usually between 3 and 4. The

secondary electrons are then focused onto a second dynode, which sits at about 100 volts positive with respect to the first dynode. When these electrons which have gained 100 eV of energy strike the second dynode the charge multiplication process is repeated and one has even more electrons, which are then attracted to a third dynode. This process is repeated for ten or more dynodes.

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To summarize, we have the focusing electrode, which sits at about 100 volts positive. The electrons are accelerated to about 200 electron volts and hit the first dynode. The dynodes are special electrodes that are coated with a special type of material, such as cesium antimony or silver manganese. For each electron striking the dynode, 3 or 4 electrons are released, multiplying the charge. The secondary electrons are then focused and accelerated toward another dynode, repeating the process. Most photomultiplier tubes will have 10 dynodes so the process is repeated 10 times or the total charge multiplication will be a factor of 4^{10} , which is equal to 10^6 or 1 million. Therefore the charge of one electron will be amplified by a factor of 1 million.

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When the electrons leave the last dynode, the charge is then collected onto an anode producing an output pulse.

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The total multiplication of the system depends upon the high voltage that has been applied and typically will vary as about the seventh power of the applied high voltage. This means that if the detector is to be stable, the high voltage power supply must be very well regulated.

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The dynode structures of a number of typical photomultiplier tubes are shown here and on the next slide. One of the oldest of the dynode structures is the box and grid dynode structure.

A much newer design is what is known as a venetian blind dynode structure. Although the use of this dynode structure is limited because the large capacitance between the dynodes results in relatively slow response times, it does have one significant advantage. When one has high counting rates the demand for charge coming from the last dynodes often exceeds the ability of the dynode to produce the charge resulting in a non-linearity in the amplification process as the count rate is increased. The venetian blind dynode structure provides significantly better stability as a function of count rate than the other photomultiplier designs.

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Some other dynode structures include the focused linear grid dynode structure and the circular grid dynode structure, which is probably the most common design. The circular grid design is commonly called a squirrel cage.

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This is a photograph of a typical 10 dynode circular grid photomultiplier tube. Notice the many pins in the tube base. Each dynode requires a separate voltage.

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This is another view of the circular grid design with the glass cut away and the screen taken off of the circular dynode structure.

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This is a picture of the end of the photomultiplier tube showing the focusing grid structure.

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In order to increase the light collection efficiency some photomultiplier tubes are made with an enlarged end region. In this case the diameter of the photocathode is 7 ½ centimeters. Photomultiplier tube are made as large as 12 ½ centimeters. Note the reddish color on the end. This is the photocathode. If the phototube has developed a leak and has lost its vacuum, the air will turn this reddish color into a transparent color.

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Each dynode, the focusing electrode, and the anode require a different voltage, therefore, rather than having 11 or 12 different power supplies, one generally uses a voltage divider to supply the different voltages. The voltage divider is simply a resistor chain used to divide the high voltage. The resistor chain is usually built into the tube socket.

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A diagram for a typical voltage divider for a photomultiplier tube with ten dynodes is shown here. As one can see, the total resistance of the system would be approximately 6 MΩ. If one applies a voltage of 1,000 volts, this means that the power supply must be capable of supplying approximately 0.5 milliamp of current.

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The voltage divider is frequently built into the base of the tube socket as shown here. This particular photomultiplier tube setup is one that we built in our laboratory.

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This slide shows a commercially made tube base, again with the voltage divider built into the base of the photomultiplier tube.

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The output pulse from the photomultiplier tube is a pulse of charge. The rise time of the charge pulse is determined by the activation processes in scintillation crystal and is typically measured on the order of nanoseconds. The decay of the pulse charge is determined by the mean lifetime of the excited levels in the scintillator. These life times range from microseconds for some of the inorganic materials to as low as a few nanoseconds for the plastic and liquid scintillators. The pulse of charge is usually converted to a voltage pulse in the preamplifier and then the decay time of the charge pulse becomes the rise time of the voltage pulse.

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Resolution

The resolution of any system is defined as the full width of the peak at one half of the maximum height of the peak or FWHM in energy divided by the energy of the peak times 100%.

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An example is shown in this slide. Here a Cs-137 spectrum was recorded with a sodium iodide detector. The photo peak is at 661.7 keV. In this case, the FWHM is 43.3 keV and the resolution of the photo peak is 6.5%. For sodium iodide, Cs-137 is the source typically used to determine the resolution of the system.

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For scintillation detectors, the resolution will be proportional to the square root of the total number of electrons reaching the first dynode.

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Factors that affect the resolution in a scintillation detector are first the energy of the radiation. Obviously, the more energy in the radiation striking the detector and deposited in the detector, the more photoelectrons will be produced.

Second is the conversion efficiency. How efficient is the detector at converting the energy deposited to usable light?

Third, is the collection efficiency of the system. How efficient is the detector at collecting the light and getting it to the photocathode surface? One way of improving the efficiency is to coat the outside of the scintillator with a white material such that when light strikes the surface, it is re-emitted back into the detector.

Fourth, what is the transparency of the scintillator? If the light is absorbed before it gets out of the detector it does not do any good.

Fifth, what is the sensitivity of the photocathode? In other words, how many light photons must hit the cathode to produce a photoelectron?

And finally, what fraction of the photoelectrons emitted by the photocathode actually reach the first dynode? This is a function of the adjustment of the focusing grid.

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Factors such as the energy of the radiation and the properties of the scintillator usually can not be adjusted. However, two factors that can be varied to obtain the optimum resolution in the scintillation detector are first the focusing grid and the high voltage. The easiest way to optimize the focusing grid is to observe the output pulse of the photomultiplier tube with an oscilloscope and adjust the voltage on the grid to obtain the maximum pulse height. If an oscilloscope is not available, one can look at the photo peaks in a spectrum. The higher the energy or channel number of the photo peak, the more electrons from the photocathode are striking the first dynode.

The second factor that one can adjust is the high voltage itself. However, changing the high voltage also changes the amplification of the phototube and to obtain optimum resolution one must do an energy calibration at each setting of the high voltage. This becomes very tedious and time consuming.

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Rather than recalibrating the system for each setting of the high voltage, one can optimize the high voltage by looking at a spectrum such as Co-60. Cobalt-60 has two photo peaks that are close enough together that they cannot be completely resolved with a scintillation detector. If one takes a look at the peak of the 1.17 MeV photo peak and compares that to the valley between the two photo peaks and takes a ratio the number of counts at the peak height to the number of counts in the valley, one can obtain a measure of the resolution of the system. The greater the peak to valley ratio, the better the resolution.

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This table shows an example of the peak to valley ratio as a function of the high voltage for a given NaI detector. Here, five voltages were tried, varying from 1130 volts to 1440 volts. For each voltage setting, the amplifier gain had to be readjusted to keep the spectrum and the photo peaks in the same relative location on the multi-channel analyzer. One can observe the peak to valley ratio varying from 8.5 up to a maximum of 10.1. Increasing the high voltage above 1340 volts caused the peak to valley ratio to drop off very rapidly to 5.0

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Applications of scintillation detectors.

One of the most common applications of scintillation detectors is to detect gamma rays and measure their energy. For this purpose the most common detector is the sodium iodide.

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The most commonly encountered NaI detectors are the integral units where the scintillation crystal is permanently mounted to the photomultiplier tube and sealed into one integral package. Many sizes are available. Some of the more common sizes are shown here in this diagram. Among the more common sizes are a five centimeter diameter by five centimeter high crystal mounted to a 5 centimeter ten stage photomultiplier tube.

Another common type often encountered is the 7 ½ centimeter diameter by 7 ½ centimeter high scintillation detector mounted to a 7 ½ centimeter diameter phototube. Most of these integral units will incorporate a magnetic shield in the covering. However, some of the older units, especially some of those made by the Harshaw Company did not incorporate the magnetic shields. Without the magnet shield, the phototubes are sensitive to the earth's magnetic field and the gain of the system will vary as the direction of the tube is changed.

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When measuring the activities of sources a variety of geometries can be used. One of the more common geometries that is frequently shown in the literature is displayed here. In this case, one is using a point source located 25 centimeters above the top of the detector. This is the standard geometry used by manufacturers when measuring the resolution of the detector. Because the source is located so far away from the detector all the photons enter the detector perpendicular to the end. This results in the best resolution. However, because the source is located so far away from the detector, there is only a very small probability that a gamma ray will hit the detector. In other words, this is a low geometry system. A more common practice would be to place the source directly on top of the detector.

Most sources used in actual practice are not point sources, but rather are discs as shown here. The source is commonly placed directly on top of the detector. However a good practice would be to place a thin sheet of plastic or some other low Z material between the source and detector to serve as a beta shield. In this case, the beta particles would be stopped in the plastic producing a minimum of bremsstrahlung radiation that would complicate the gamma ray spectrum.

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Another common geometry is the one used to measure liquid samples. In this case sample might be a one liter bottle placed directly on top of the detector.

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Another geometry that is used for counting samples is the Marinelli beaker. This geometry is commonly used for large samples and increases the detection efficiency by surrounding the detector.

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A diagram of a Marinelli beaker is shown here. It is a large beaker, either 1, 3, or 4 liters in size, and has a large hole or cavity in the center. The beaker is then placed directly over the detector and completely surrounds the detector.

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Another geometry frequently used to increase the detection efficiency for small samples is the well type crystal.

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Here a hole is drilled into the detector and the sample is placed into the well. This increases the solid angle for detection. However it does have some disadvantages. One disadvantage is that high energy photons may pass completely through the walls of the detector without interacting. The second disadvantage is that if one two low energy photons that are in coincidence, that is they are emitted from the source within a microsecond of each other and both interact in the detector, the energy from the two gamma rays can be summed together making the event look like one high energy photon.

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This is shown here where the source is emitting two photons with similar energies in a cascade. In this case, the half life of the gamma ray is 1.49 ns following the decay Iodine-125 by electron capture. When the Iodine-125 decays by electron capture, a 27.5 keV X-ray is emitted. If one has source outside of the detector one gets a peak due to the gamma rays and X-rays and a very small sum peak, which is the sum of the energies of the two low energy photons. However, if the source is in the well, one gets a much higher probability of detection of both photons as shown in the peak, which is much larger, but at the same time one also gets a large sum peak, which looks like a second gamma ray and sometimes this can complicate the analysis of the spectrum.

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Other Applications of Scintillation Detectors.

Among some of the other applications for scintillation detectors are gamma cameras. These are devices that not only detect the gamma rays, but also will give some information about the origin of the gamma ray.

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One type of gamma camera is shown here. In this example, a large slab of sodium iodide is monitored by a number of different photomultiplier tubes. It is placed behind a lead collimator. The purpose of the collimator is to limit the

gamma rays detected to those gamma rays that are entering perpendicular to the sodium iodide crystal. By comparing the signals from the different photomultiplier tubes, one can determine where in the sodium iodide crystal the particular gamma ray interacted.

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The results are shown here, where one is looking at a skeleton of a person that has been injected with the radioisotope technetium-99m.

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Another example of gamma cameras is positron emission tomography or PET.

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In this case a large ring of sodium iodide detectors are arranged in a circle.

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In this case the patient is injected with a chemical compound that contains a relatively short lived positron emitter. When the positron interacts in the surrounding tissue it annihilates producing two half MeV photons that are emitted at 180 degrees to each other. The sodium iodide detectors are operating in coincidence so that when two detectors both detect a 0.511 MeV photon at the same time one knows that the positron emitter is on a straight line between the two detectors as shown here. By analyzing a large number of events, one can locate where in the body the compound is located.

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A picture of the PET device is shown here. The patient is placed on the table and slowly passed through the ring of detectors. Since the positron emitters are concentrated in the organ or tissue of interest, one can pinpoint their location.

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A similar device often used in medical diagnostics is the CAT scan device. Here an electron accelerator focuses a beam of electrons onto a target producing x-rays. The x-rays are then collimated and focused through the body to a detector. By rotating a device around the body, one can pinpoint variations in the density of the body such as bones or tumors.

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Another application of scintillation detectors in the laboratory is the use of liquid scintillation detector systems. These systems are usually used to detect low energy beta emitters such as tritium or carbon-14 or higher energy beta emitters such as potassium-40.

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These systems use small amounts of liquid scintillator placed in vials such as shown here. This vial contains 14 ml of a liquid scintillator.

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The sample, in this case a wipe used to check for loose surface contamination, is placed directly in the scintillator as shown here. This has the advantage in that it has a very high detection efficiency.

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The scintillation vials are then placed in an automatic counting system such as the Packard Tri-carb system shown here.

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Most automatic liquid scintillation counters have three separate systems that must be maintained. First the scintillation detector electronics, and data acquisition systems; second, the refrigeration system; and third the sample changer.

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A diagram of a typical data acquisition system found in many older systems is shown here. The system uses two photomultiplier tubes, one on each side of the liquid scintillator vial. This not only increases the detection efficiency of the light, but also serves to reduce the background. When counting samples for tritium or C-14, the beta particles have very low energies. This combined with the low conversion efficiency means that very few light photons are produced. This fact coupled with the small solid angle that the vials present to the photomultiplier tube and the efficiency of the photocathodes, means that there may be only one or two electrons emitted from the photocathode per event. However, the photocathode with its low work function is continually emitting electrons, so the background from the system could be very high. These electrons are called the dark current. To reduce the background, the pulses from the photomultiplier tube are fed to a coincidence circuit and only those events that have an interaction in both photomultiplier tubes at the same time are then counted. The pulses from the photomultiplier tube are also fed to a summation circuit where they are added together and then fed to a pulse height analyzing system. The pulse height analyzing system shown here which is typical of older units consists of simply amplifiers, pulse height analyzers, and scalers.

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A similar system using a computer for analyzing the beta spectra is shown here where the pulses are fed to an ADC or analog to digital converter and then analyzed by a computer system. This type of system will be found in most of the newer liquid scintillation systems.

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Two beta spectra are shown here. The unquenched spectrum is from a clean sample, that is a sample that does not affect the performance of the liquid

scintillator. However, many materials that are placed in the liquid scintillator will either affect the conversion efficiency of the scintillator or absorb some of the light photons before they can escape from the scintillator thus reducing the pulse amplitude as shown in the quenched spectra. Some of the newer counting systems will use an external source to check for quenching and then adjust the amplifier gain to correct the counting rate.

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A second system that must be maintained in most liquid scintillation counting systems is the refrigeration system. Cooling the photocathode reduces the dark current and lowers the background. The refrigeration system is usually a mechanical system that also requires regular maintenance.

The third system is the sample changer. Since one wants be able to count many samples automatically, one needs a mechanical sample changer.

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Such a sample changing system is shown here is a Packard Tri-carb system. In the counter, approximately 200 samples can be placed in the detector and counted automatically in sequence.

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Still another application for scintillation detectors is for the detection of alpha particles.

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In this case, most detectors use a very thin crystal or powder of silver activate zinc sulfide or ZnS(Ag) coated on the face of the photomultiplier tube. Silver activated ZnS has a high conversion efficiency, but is not transparent. Therefore, these scintillators must be very thin. If the scintillator is thin then beta particles or electrons from photon interactions cannot deposit enough energy to be detected. The background in the system is due primarily to cosmic radiation and is very low. These detectors must be placed in a light tight enclosure or have a very thin, light tight window or covering. The window must be thin enough to allow the alpha particles to pass through and deposit enough energy in the detector to be detected.

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Such an alpha counting system is shown here. The sample is placed in the tray.

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The tray is then closed and the system forms a light tight chamber and the high voltage turned on.

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Scintillation detectors are also used as the probes for survey meters.

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The major disadvantage of using scintillation detectors as a probe is that they are more fragile than the typical G-M Detector and also are much more expensive. The major advantage, however, is that they are much more sensitive to gamma rays.

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One variation of the conventional scintillation detector is to replace the photomultiplier tube with the photodiode to convert light to charge. A disadvantage of this system is that one no longer has the amplification or charge multiplication from the photomultiplier tube, but must rely completely upon electronic amplification in the pre-amplifier and amplifier. One advantage, however, is that one gets a much broader range of spectral sensitivity than one can get with either S11 or bi-alkali photocathodes that one has with photomultiplier tube. This means that the system will work well with crystals such as thallium activated cesium iodide. Another advantage is the small size. One no longer has the bulky, large size of the photomultiplier tube, but rather has a very small photodiode. This, of course, can also be a disadvantage when one wants to use large crystals.

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The spectral sensitivity of a typical diode is shown here. One can see that although they will work with wavelengths as low as 440 nm, they work much better if the wavelength is longer around the range of 500-700 nm. Thallium activated cesium iodide has a peak around 560 nm, which means that it would work well with this diode. Other scintillators such as BGO also work quite well although the light output is much lower.

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Some typical shapes offered by the Bicron company are shown here. One can see the rectangular size with photodiodes on either the end or along one edge of the scintillator.

Slide 80

Typical sizes are shown here. The largest is a 18 mm x 18 mm x 6 cm long crystal.

The resolution of such a system is 8.6 keV with the Cesium 137 source. This is not as good as typical sodium iodide crystals using photomultiplier tubes, but is very acceptable.

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Another geometry is shown here, which is a detector offered by Scionix Company. Here one has a 5 cm diameter crystal attached to a photodiode.

Slide 82

Performance of such a detector is shown in this slide. One can see the 122 keV peak, the 511 keV peak from positron annihilation and the 1.238 keV peak from a gamma ray.

Slide 83

Another variation of scintillation detectors are TLD or Thermal Luminescent Dosimeters.

Slide 84

Going back to the Fermi energy level diagram as shown here, one finds that when radiation interacts with a TLD material, electrons are raised from the valence band up to the conduction band. They then decay back down to an impurity energy level that is located in the forbidden gap. But unlike ordinary scintillation detectors, where the electron can continue to decay down to the valence band, with TLD dosimeters, they are trapped at this location. The more radiation that bombards the TLD Dosimeter, the more electrons will be trapped in this forbidden gap. Upon heating the TLD, the electrons gain enough energy to move back into the conduction band and then from the conduction band most of them will drop back to the valence band and in the process they will emit light that could be detected by a photomultiplier tube.

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TLD Dosimeters come in a variety of sizes and shapes. Some small ones shown here are approximately 3 mm x 3 mm x 1 mm thick. TLD material may also be in the form of a powder or in small rods.

Slide 86

A typical TLD detector readout unit is shown here.

Slide 87

The TLDs are placed on a small heater and then moved into a light tight region. The heater is turned on, heating the TLD, producing small flashes of light that are read out by the photomultiplier tube.

Slide 88

A newer version of a TLD reader is shown in this system. The latest systems for TLD readers, use lasers to raise the electrons from the forbidden area up to the conduction band as opposed to using a heater.

Slide 89

A short summary of scintillation detectors would be as follows. First they operate at room temperature as opposed to some radiation detectors that require liquid nitrogen temperatures.

Second, they may be a very large size, as large as 50 cm x 50 cm in terms of a solid inorganic detector or size of large rooms in case of a liquid scintillator.

They are very versatile instruments. They can be used in the laboratory for measuring radiation or they may be used as hand held survey instruments.

They may have a relatively high density such as sodium iodide or BGO detectors, which means that they are then good for detecting gamma rays. This ends the module on scintillation detectors.