REVIEW OF THE PRINCIPLES RELATED TO SCINTILLATION DETECTION OF RADIOACTIVE MATERIAL

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PURDUE UNIVERSITY

Nuclear Pharmacy Programs

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Q1

- At the beginning of this presentation, to what extent would you say that you are comfortable with how a scintillation detector works?
  - A. Extremely comfortable
  - B. I kinda know what I'm doing
  - C. I bet I learned it somewhere
  - D. Not a clue

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Q2

- Scintillation detectors detect radiation that interacts with the detector by which mechanism?
  - A. Excitation
  - B. Ionization
  - C. Neither of these

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Q3

- What is the best detector for detecting alpha radiation?
  - A. GM survey meter
  - B. Single channel analyzer
  - C. Multi channel analyzer
  - D. Liquid scintillation detector

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OBJECTIVES

- Review the radionuclide gamma spectrum
- Discuss the operation of scintillation detectors
- Identify the different components of a scintillation detector and how each operates
- Differentiate between single and multi-channel analyzers
- Recognize the various aspects of a liquid scintillation detector

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REVIEW RADIONUCLIDE GAMMA SPECTRUM

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RADIONUCLIDE GAMMA SPECTRUM

- Sources which produce gamma rays generally emit gammas of various energies and intensities
- Analysis using a spectroscopy system can result in the production of a gamma-ray energy spectrum
- Unique “signature” for any given isotope – characteristic of the isotope
- Helps determine a nuclide’s suitability for use in nuclear medicine procedures
- Gives information on energy of gamma photons and the abundance (amount emitted from the specified nucleus)

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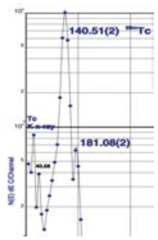
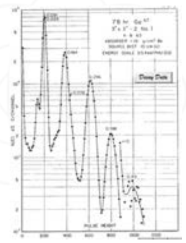


Tc-99m spectrum

Ga-67 spectrum



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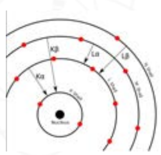
POP QUIZ

- What is a characteristic x-ray?
- When an element is bombarded with radioactivity, it might interact with an inner shell electron
  - If the energy transferred to the electron is greater than the binding energy, the electron is ejected from the atom
  - Atom has vacant inner shell electron space
  - Outer shell electrons drop down to fill the inner shell opening
  - Photons are emitted with energy level equivalent to the difference between the higher and lower energy states
  - Each element has a unique set of energy levels
  - Transition between levels is always the same = “characteristic” of that element



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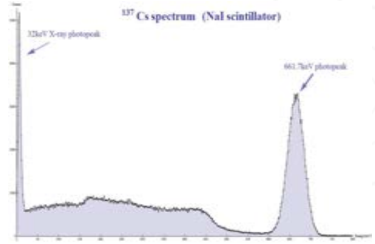

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CRYSTAL SCINTILLATION DETECTORS

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CRYSTAL SCINTILLATION DETECTORS

- Instrument for detecting and measuring ionizing radiation
  - Utilizes the excitation effect of radiation on a scintillating material
  - Energy converted to light pulses of intensities corresponding to the original energy of the gamma photon
- Components
  - Scintillator
  - Charge-coupled device
  - Photodetector
  - Electronics for processing

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DETECTORS: WELL COUNTERS AND PROBES

- Detector styles:
  - Well counters provide increased counting efficiency because crystal "surrounds" the source
  - Scintillation probes have flat faced crystals with no well
- Type of detector used is dependent on the use of the equipment

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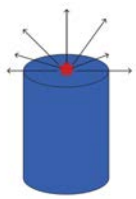
DETECTORS: WELL COUNTERS AND PROBES



- Detector styles:
  - Well counters provide increased counting efficiency because crystal "surrounds" the source
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DETECTORS: WELL COUNTERS AND PROBES

EFFICIENCY

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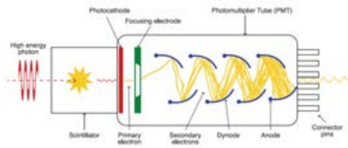
GAMMA PHOTON DETECTION



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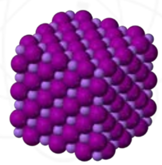
CRYSTAL SCINTILLATION DETECTORS

- External scintillation detectors are based upon the interaction of radiation with a solid crystal detector or scintillator
- Scintillator is a luminescent material that when struck by an incoming particle, is able to absorb the energy and scintillate
  - Scintillate – re-emit absorbed energy in the form of light



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CRYSTAL SCINTILLATION DETECTORS

- Sodium iodide doped with 0.1– 0.4% thallium detectors are low cost and commonly used
  - Tl acts as an "activator" for the crystal
  - Tl doping is done to help enhance the visible light output of the crystal
    - Luminescent light is quickly produced (within microseconds)
    - Allows for different scintillation events to be distinguished in time
- Sodium iodide scintillators have some of the greatest light output of all scintillator types

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CRYSTAL SCINTILLATION DETECTORS

- Crystals are hygroscopic so must be hermetically sealed in aluminum containers
  - Absorbed water causes color changes
  - Reduces light transmission
- Sodium iodide crystals are surrounded by a lead shield to decrease background radiation
  - ~8.5 cm lead
- Geometric efficiency of detection is maximized by inserting a radioactive sample into a "well" bored in the center of the detector
  - Efficiency can approach 99% for certain isotopes

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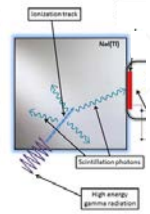
COMPONENTS - SODIUM IODIDE CRYSTAL

- Photon enters crystal
- Deposits energy within crystal - leads to excitation of the electrons in the crystal
  - Photoelectric effect
  - Compton scatter



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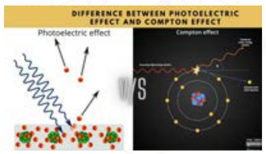
RADIATION INTERACTION WITH MATTER

- Photoelectric effect
  - Single electron absorbs the entire energy of an incident poton
  - Photons are lost as soon as the energy is transferred to the electron
- Compton scatter
  - Occurs at mid-energy levels
  - Photons contact an electron but only a portion of the energy is transferred
  - Photon is scattered at lower energy level
    - Still retains potential to interact with other electrons



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COMPONENTS - SODIUM IODIDE CRYSTAL

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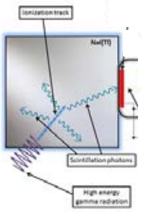
- Photon enters crystal
- Deposits energy within crystal - leads to excitation of the electrons in the crystal
  - Photoelectric effect
  - Compton scatter
- As "excited" electron returns to its normal state, it releases the excess energy in the form of a photon of visible light (scintillation)
- Intensity of pulse is directly proportional to the energy of the photon



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COMPONENTS – SODIUM IODIDE CRYSTAL

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- Each light photon produced is approximately 3 eV
- 20 – 30 light photons are produced per keV of energy transferred to the crystal material
- Inside of crystal casing is reflective to increase the capture rate of the light photons that are produced
- Radiation energy converted to light energy
- Now what?

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GAMMA PHOTON DETECTION

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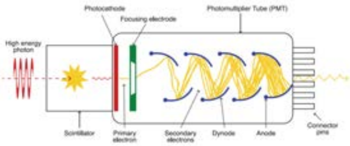

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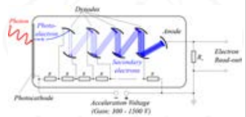
PHOTOMULTIPLIER TUBE

- Once the light photons are emitted, they must be converted to something that the electronics of the equipment can utilize
  - Commonly used wherever low levels of light must be detected
- Photomultiplier tube is an extremely light-sensitive vacuum tube
  - Photocathode
  - Dynodes



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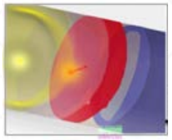
COMPONENTS - PHOTOCATHODE

- Visible light energy is channeled into the photocathode
  - First component of the photomultiplier (PM) tube
  - Crystal and PM tube are optically coupled
- Photocathode contains combinations of cesium, rubidium and antimony
  - When illuminated even by low levels of light, the photocathode releases electrons readily
  - The kinetic energy of the emitted electrons is exactly the energy of the incident photon minus the electron binding energy
- Entry of light photons into the photocathode result in the emission of electrons
  - 1-3 photoelectrons per 7-10 light photons
  - The number of electrons produced will be proportional to the energy of the original photon



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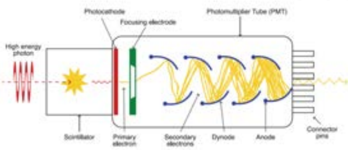
GAMMA PHOTON DETECTION



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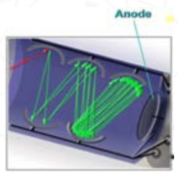
COMPONENTS - PHOTOMULTIPLIER TUBE

- PM Tube collects the photoelectrons produced by the photocathode
  - Electrons are attracted to a series of dynodes, each about 100 V more positive than the previous one
  - Usually 10 dynodes in the chain
- High voltage (500 to 1500 volts) is applied to the PM Tube resulting in multiplication of the original electron packet as it moves to the next dynode



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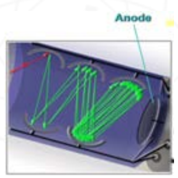
COMPONENTS - PHOTOMULTIPLIER TUBE

- Dynodes produce secondary electrons which"multiply" the moving electrons, with approximately 4-5 electrons ejected for each electron that hits
- "Packet" of electrons produced will be attracted to the next dynode in the chain
- Total amplification is related to the amount of amplification at each dynode
  - This can be altered by changing the voltage applied to the PMT
  - Can easily amplify by 1,000,000 times or more



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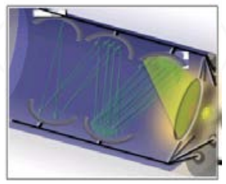
COMPONENTS – PHOTOMULTIPLIER TUBE

- Electrons collected at the last dynode are converted to an electronic signal or pulse
- Pulse is fed into a pre-amplifier at the base of the detector
  - Amplifies weak pulses
  - Shape pulse for optimal processing
- Number of pulses per unit time gives information about the intensity (amount) of radiation
- Pulses produced are passed on to the electronic component of the detector, the pulse height analyzer (PHA)



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WHERE ARE WE?

- Up to this point, all interactions have occurred in the detector

- Next, we will push the pulse to the electronic component of the detector for analysis

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COMPONENTS – PULSE HEIGHT ANALYZER

- We now have pulses that correspond to the original energy of the photon that interacted with the crystal, but what good does that do us?
  - This can give us a relative "amount" of radioactivity
  - Shows as counts: more counts = more activity
- In addition, because of the proportionality of this equipment, we now also have the ability to segregate the pulses into channels based on the energy of the original photon
  - We will have multiple photons across the gamma spectrum of the isotope
  - How can we use this information to give more information about the isotope that deposited those photons in the detector?

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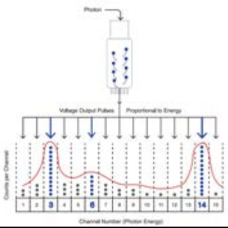
COMPONENTS – PULSE HEIGHT ANALYZER

- The pulse height analyzer (PHA) is the electronic component of the detector
  - PHA has "channels" or "divisions" between 0 and ~1000
  - When entering the pulse height analyzer, each pulse is segregated based on its incident photon energy and allotted to a particular channel within the system
  - Each pulse is automatically moved into the correct channel and counted along with other pulses originating from photons of the same energy



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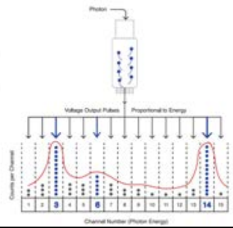
COMPONENTS – PULSE HEIGHT ANALYZER

- If these PHA divisions can essentially be "assigned" to correspond to a specific energy unit, it is possible to also define a relationship between the pulse outputs and the original gamma ray energy
  - CALIBRATION of the scintillator



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COMPONENTS – PULSE HEIGHT ANALYZER

- Since detection and multiplication can occur for any gamma photon which enters crystal, regardless of the source, it is sometimes necessary to OMIT some photon pulses from registering
- PHA has a gain control for modifying pulse amplitude to allow acceptance or rejection of certain pulses
- Allows us to set controls called DISCRIMINATORS which allow us to sort pulses
  - LOWER LEVEL DISCRIMINATOR (LLD) - no pulses below this "base" will be counted, even if they enter the crystal
  - UPPER LEVEL DISCRIMINATOR (ULD) – no pulses above this "base" will be counted, even if they enter the crystal
- The space between the LLD and ULD is usually referred to as a "window"

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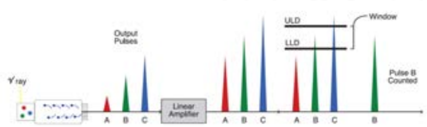
COMPONENTS – PULSE HEIGHT ANALYZER

- Most commonly, you use the PHA to set a "window" which identifies which counts you want to analyze
- An input pulse from the detector must fall within the window to be counted



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COMPONENTS – PULSE HEIGHT ANALYZER

- PHA operates in two different counting modes, depending on how the equipment is set up
  - Differential mode:
    - Only pulses of preselected energies are counted
    - Based on setting upper and lower discriminators
  - Integral mode:
    - Photons of any energy above a predetermined value (threshold) are counted
    - No upper level discriminator is used
    - Sometimes referred to as "wide open window"

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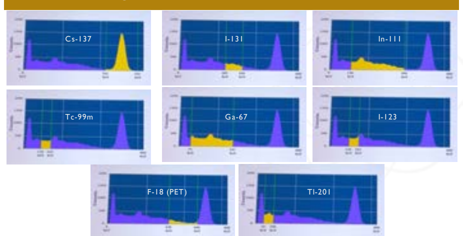
DIFFERENTIAL MODE



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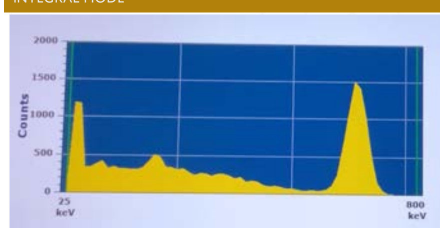
INTEGRAL MODE



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CALIBRATION

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SCINTILLATION DETECTORS - CALIBRATION

- Calibration is done using a known isotope, ideally with one distinct photopeak
- During calibration, our goal is to place the photopeak of this isotope in the channel that we would like to correspond to its energy
  - Example: if source has 300 keV photopeak, we want to move it to channel 300 (if we are doing 1 keV/channel), channel 150 (if we are doing 2 keV/channel) and channel 600 (if we are doing 0.5 keV/channel)
- Once calibrated, we have established a relationship between energy and channel number
- Once we know this, we will be able to IDENTIFY any isotope that we try to read on our machine by looking at the number of counts in the channel that corresponds to its known photopeak energy
  - This is a major difference between scintillation detectors and gas filled detectors

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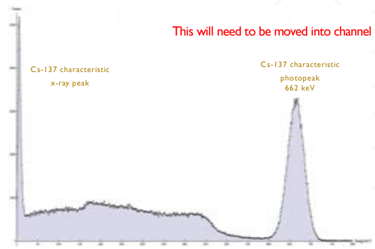
This will need to be moved into channel # 662



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MOVING THE PEAK

- So, how do you "move" a photopeak?
- Utilize the electronic components of the PHA
- Output of scintillation detectors is primarily controlled by two components:
  - Amplifier
  - Voltage
- These two settings work together to increase signal output of information obtained in the detector

↑ AMPLIFICATION ↓ VOLTAGE

↓ AMPLIFICATION ↑ VOLTAGE

↔ AMPLIFICATION ↔ VOLTAGE

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MOVING THE PEAK

- In most scintillation detectors, amplification is pre-set and not something that is routinely changed
  - The detector is detecting, the amplification is amplifying now we just need to adjust the display of the data to fit on the scale we are using
- Adjustment manipulations are done using voltage settings

↑ VOLTAGE = Peak shifts to right

↓ VOLTAGE = Peak shifts to left

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SINGLE CHANNEL CALIBRATION

- To calibrate the SCA, assuming a 1 keV / channel goal using a Cs-137 source is a bit more complicated since you can't visualize the peak at any time during this process
  - Only data obtained is counts
- We will need to use number of counts to help identify the peak
  - Peak = largest area under the curve
  - Area under curve = counts
  - Peak = largest number of counts
- How do we know what counts are from the peak?

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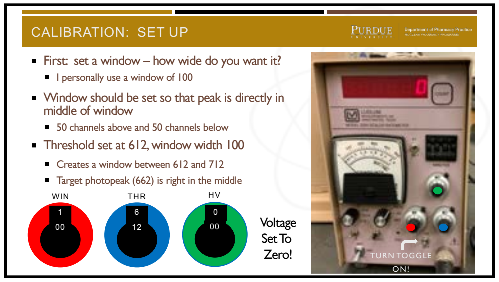
CALIBRATION: SET UP
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First: set a window – how wide do you want it?
I personally use a window of 100
Window should be set so that peak is directly in middle of window
50 channels above and 50 channels below
Threshold set at 612, window width 100
Creates a window between 612 and 712
Target photopeak (662) is right in the middle
WIN
1
00
THR
6
12
HV
0
00
Voltage Set To Zero!
TURN TOGGLE ON!

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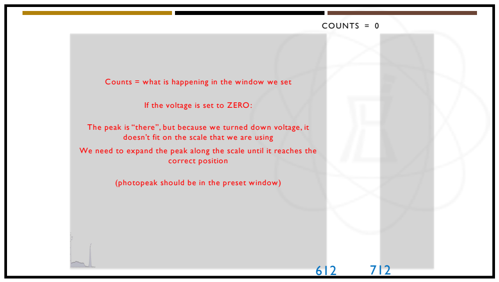
COUNTS = 0
Counts = what is happening in the window we set
If the voltage is set to ZERO:
The peak is "there", but because we turned down voltage, it doesn't fit on the scale that we are using
We need to expand the peak along the scale until it reaches the correct position
(photopeak should be in the preset window)
612
712

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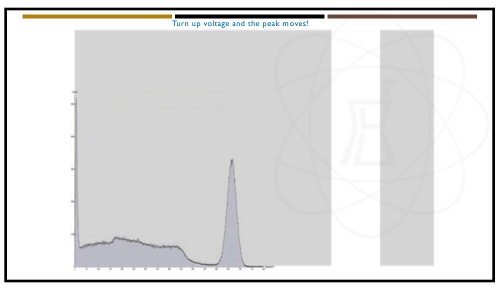
Turn up voltage and the peak moves!

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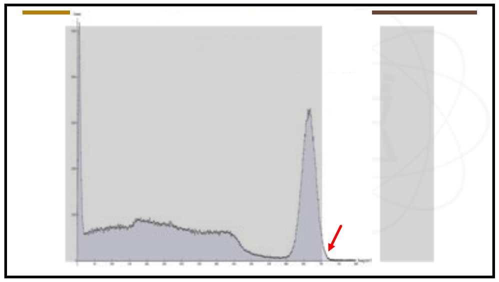

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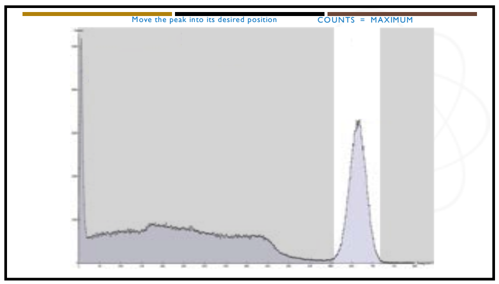
Move the peak into its desired position
COUNTS = MAXIMUM

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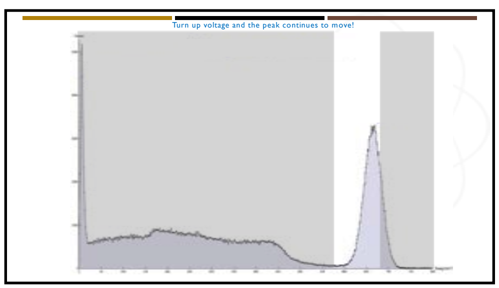
Turn up voltage and the peak continues to move!

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CALIBRATION

- The voltage setting where the peak falls in the center of the window (highest counts) = operating voltage for the equipment
- The 662 keV photopeak is now placed in/near the 662nd channel
- 1 keV / channel calibration
- Once a machine is calibrated, we will take a 1 minute "reference" count
  - Return all settings back to where we started:
    - Window = 100
    - Threshold = 612
    - HV setting = the operating voltage you just determined
  - This number will be used for comparative purposes on a daily basis to assure machine is working / still calibrated

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DAILY CONSTANCY

- On a day-to-day basis, before using the scintillation detectors for any type of data collection or verification, we must assure that it is still working correctly
  - Major potential problem = energy surges that may damage the PMT
    - PMT not working = no multiplication of electrons = inaccurate output
  - Staff may like to "adjust" settings to get a better output
- Depending on how you use your machine, you may need to show that your machine is still calibrated, but you also need to prove that the electronics are working correctly before collecting any data
- A recalibration procedure (while not difficult) is generally not something we do everyday
- We can prove that our machine is still calibrated AND that the equipment is working correctly with a single daily test
  - Daily constancy test

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DAILY CONSTANCY

- Using same settings you used when *calibrating* your machine
  - Operating voltage
  - Threshold
  - Window
- Place the Cs-137 source in the well
- Take a 1 minute count
- Compare this count to your 1 minute reference count that was obtained on the day you calibrated your machine
- Determine the percent variance

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PERCENT VARIANCE

$$\% \text{ Variance} = \frac{\text{Calibrated reading} - \text{Today's reading}}{\text{Calibrated reading}}$$

Up to 10% Variance is acceptable

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PERCENT VARIANCE

- You will need to calculate this variance each day
  - If greater than 10%, you will need to recalibrate machine
  - If number is significantly off, there is a possibility that the machine may be broken
  - Generally should identify problem to RSO
- Easiest way to "check"
  - On calibration date, take 1 minute reading (reference reading)
    - Multiply by 0.9 to get the -10% value
    - Multiply by 1.1 to get the + 10% value
    - Post "range" – if daily constancy test falls between these 2 numbers, the machine is acceptable for use

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NOTES ON CALIBRATION

- Machine can be calibrated in different ways
  - If you plan to use your machine for identification of isotopes
    - We need to make sure you establish an accurate energy/channel relationship
    - Requires calibration specific to the isotope you are using as a calibration source
    - Window should be centered around the characteristic photopeak for this isotope
    - Window width is arbitrary, but shouldn't be too wide
  - In many pharmacies, the machine dedicated for isotope identification is going to be the MCA, not the SCA
    - Much easier to set up and calibrate
      - Can visualize the peak when calibrating, but also when an unknown is placed in the well
      - Identification of unknown isotope simply involves toggling to the top of the peak and determining which channel it falls into
    - Computer interface allows for more accurate data

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NOTES ON CALIBRATION

- Machine can be calibrated in different ways
  - If you do not plan to use your machine for identification of isotopes
    - Energy/channel relationship is not as critical
      - Operation of machine without isotope specific window settings allows for ability to detect any isotope, no matter where it falls on the energy scale
      - If the desired photopeak placement is off a bit, it won't matter significantly as long as it doesn't fall outside the wide open window
    - Most facilities will still calibrate specific to the isotope you are using as a calibration source, however, accuracy is not as critical
    - Some facilities simply take the 1 minute final count after calibration by changing the window settings to a threshold of 50 or so and turning the window settings off
      - "Wide Open Window" count doesn't indicate where the photopeaks are, but will indicate how many counts should be seen if the machine is operating correctly

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NOTES ON CALIBRATION

- Most facilities "recalibrate" using this procedure every quarter in a calendar year
  - Done with other operational tests (discussed later) to assure that data output is correct
  - Usually, HV settings should not change significantly from quarter to quarter
    - May be able to modify calibration procedure to only doing a "fine tuning" protocol to verify operating voltage
- Whenever the machines are calibrated (recalibrated), the HV setting is documented in the facility computer system
  - It is important that this setting NOT be changed unless part of a documented recalibration procedure
  - This is often a regulatory check point during inspections!

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SINGLE VS. MULTI CHANNEL ANALYZERS

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SCINTILLATION DETECTOR - DATA OUTPUT

- When operating this equipment for quantification, data will be provided in "counts"
  - Count = one photon detected in the crystal
  - Number of counts will be dependent on how the electronics (PHA) are set up
    - Only events that occur within the "window" that is set will be included in the count output
    - If any other events outside the window have occurred, they will be ignored
- Two main types of electronic displays that can be used:
  - Multi-channel Analyzer (MCA) – you will see the visual spectrum of the isotope
  - Single-channel Analyzer (SCA) – you will see the counts only. Location of the peak must be inferred from the operating settings
- COUNTS are not 100% equal to DISINTEGRATIONS!

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SINGLE CHANNEL ANALYZER

- SCA provides data in the form of COUNTS
  - Counts = number of interactions identified by the electronics of the equipment which fall within the LLD and ULD that are set by the user
  - Counts DO NOT give any readily available information about what the distribution of photon energies would be, other than the knowledge that they have to fall within the window which has been set
- In theory, if the machine has been calibrated, one can also manipulate settings to identify what the energies are of the photons, but this is generally a considerable amount of work

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SINGLE CHANNEL ANALYZER

- SCA counts can also be expressed using a rate meter
  - Needle deflects based on the accumulation of counts
  - Also provided in cpm
  - Useful when calibrating machines, but not routinely used when operating the machine for basic counting operations.

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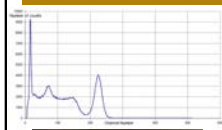
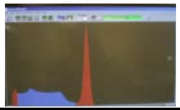
MULTI CHANNEL ANALYZER





- MCA provides data in the form of COUNTS and a graphical representation of the distribution of those counts across the various channels or divisions (0 – 1000)
- Entire gamma spectrum is visualized, although only some fraction of it may be incorporated into the total counts obtained, depending on how the window is set
- Moving electronic cursor to the top of the photopeak allows for identification of the energy (assuming the machine is calibrated appropriately)
- Much easier to identify unknown isotopes
- Computer driven operation also allows for more accurate data output

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SCINTILLATION DETECTOR OUTPUT

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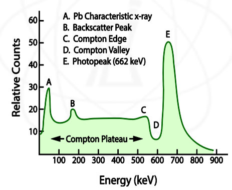
GAMMA SPECTRA

- Significant number of gamma photons interact via the photoelectric effect
  - Full energy converted after interaction with crystal
  - Called the "photopeak"
- Some gamma photons interact via Compton's scattering
  - Scattered photons are detected at lower energy than the original photon energy, depending on the angle of scatter
  - Energies of Compton's scatter electrons range from 0 to E_{max}



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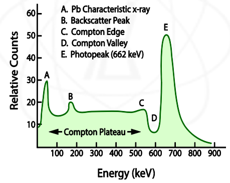
GAMMA SPECTRA

- Compton Edge:
  - When full backscatter occurs, some energy is lost, but this is the highest energy that can be deposited as a result of Compton's scatter
- Compton Valley
  - "Dip" that occurs just before the photopeak
    - Since the maximum energy that can be deposited from scattered photons occurs at the Compton Edge, there are essentially no Compton photons generated in this range
- Compton Plateau
  - Visual representation of the photon interactions that occur via Compton's scatter



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OTHER CONSIDERATIONS – IODINE ESCAPE

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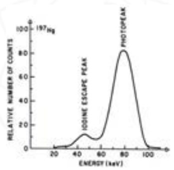
- When counting isotopes with lower energy gammas, an *iodine escape peak* may be generated
  - Photoelectric absorption interacts with the iodine atoms in the crystal
  - Release a characteristic iodine x-ray of approximately 30 keV
- Usually not seen with higher energy photons, as the initial absorption occurs deeper in the crystal and the x-ray is not detected



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OTHER CONSIDERATIONS – LEAD ESCAPE

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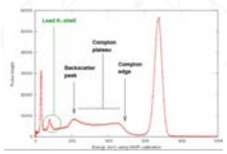
- *Lead escape peak* can also be generated as a result of interactions with lead shielding that surrounds the detector
  - Characteristic lead x-ray occurs around 72 keV
- Can be minimized by increasing the space between the crystal and the shielding material



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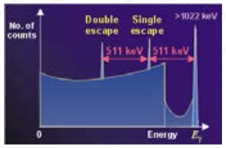
OTHER CONSIDERATIONS – PAIR PRODUCTION

- Gamma photons with more than 1.02 MeV energy may undergo pair production in the detector
  - Positive and negative electron pair produced
  - Positron moves and comes to rest when combining with an electron
    - Production of 2 x 511 keV gamma photons
- Possible outcomes:
  - Both 511 keV photons are absorbed, they are recorded in photopeak at the energy of the incident photon
  - If only one photon deposits energy, a "single escape peak" is formed at 511 keV less than the incident photon
  - If both photons escape, a "double escape peak" is formed at 1022 keV less than the incident photon



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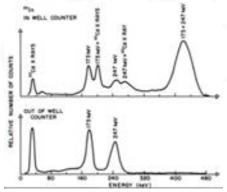
OTHER CONSIDERATIONS – SUMMING

- Coincidence peak / Summing
  - If more than one photon is absorbed at the same time in the detector, it can be recognized as a single event, not two separate ones
  - Results in photopeaks that have energies that are greater than any characteristic peak that is expected
    - Generally has the energy equal to the sum of the expected photopeak energies



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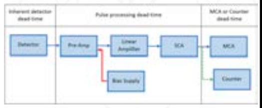
OTHER CONSIDERATIONS – DEAD TIME

- Dead time
  - The minimum time interval that two consecutive counts must be separated by in order to be considered two separate events
  - Also called resolving time
  - Can be due to:
    - Intrinsic detector deadtime
    - Electronic processing of pulse
    - Analog to digital conversion
- Scintillation detectors:
  - 0.5 – 5 µsec



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QUALITY CONTROL TESTING

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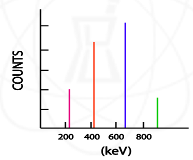
GAMMA SPECTRA

- Ideally, the gamma ray energy entering the crystal would be completely absorbed and converted to light energy via the photoelectric effect
  - Results in each gamma ray photon of a particular energy producing the same pulse size
  - Spectrum would look like straight lines



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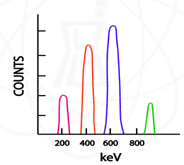
GAMMA SPECTRA

- In reality, when read in a scintillation detector, the peaks appear to be broader
- Why?
  - Statistical variations
  - Each absorbed keV of energy results in about 20-30 light photons
    - 7-10 of these photons must be detected to release 1-3 photoelectrons from the photocathode
  - Not all photons from the detector reach the photocathode
    - The number of photoelectrons resulting from one gamma photon will differ from one event to another
  - In the PMT, the number of photons emitted from the sequential dynodes is a range (2-4) not a constant number
    - Slight variation in the resulting placement on the calibrated scale



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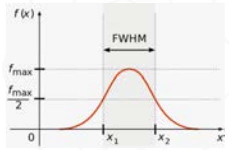
ENERGY RESOLUTION

- Resolution – ability to separate two gamma peaks that are close to each other
  - Important when determining unknowns
- Calculated by determining the ratio of the full width of the photopeak at half-maximum of the energy peak
  - Usually expressed as a percentage of the photopeak energy
  - Ideally, would like the FWHM to be <10%



$$FWHM = \frac{X_2 - X_1}{F_{max}} x\ 100$$

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EFFICIENCY

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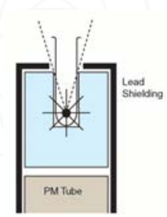
EFFICIENCY

- No machine is 100% efficient
- Some photons will be lost (not detected) as a result of a variety of factors
  - Did photon lose energy before it entered the crystal?
  - What happens to photons traveling straight upward from the source?
  - What happens if the photon doesn't get stopped by the crystal?
  - What effect does energy have on this?
  - How is the machine set up?
    - Window settings



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EFFICIENCY

- Our machine will give us data as "counts" – the number of events it sees
- Lost events are still considered part of the total activity – our machine just didn't see them for whatever reason
- To get the most accurate information from the equipment, we must know what percentage of the actual (truly occurring) events are being detected by our equipment
  - Reliant on positioning, isotope used, etc
- If we can figure this out, we can convert the data our machine gives us (in counts) to the actual number of disintegrations that have occurred in the source

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EFFICIENCY

- Any source we use will have a calibration activity and date
- We can determine (using the decay equation) how much activity is present (in disintegrations per minute) in the source at the time you are determining efficiency
- We then count the source in our machine for 1 minute
- Comparison of what our machine was able to detect (counts/minute or CPM) and what was actually happening and what the machine SHOULD have seen (disintegrations/minute or DPM) gives us the efficiency of our machine

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EFFICIENCY

$$\text{Efficiency} = \frac{\text{cpm}}{\text{dpm}} \times 100$$

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LIQUID SCINTILLATION DETECTORS

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LIQUID SCINTILLATION DETECTORS

- Some types of radiation are unable to enter the types of detectors that we have previously discussed
  - Alpha and low energy beta radiation does not travel far enough or have the ability to penetrate the outer components of a detector
- If a facility utilizes these types of radionuclides, a different detector is required to adequately detect radiation

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LIQUID SCINTILLATION DETECTORS

- In liquid scintillation counting, a radioactive sample is placed in a liquid scintillation counting cocktail
  - Sample is actually mixed with the fluid in a vial
  - Cocktail contains an aromatic, organic solvent and the scintillating compound (also called a fluor)
- This system maximizes the chance that the radioactivity will come in contact with the scintillator

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LIQUID SCINTILLATION DETECTORS

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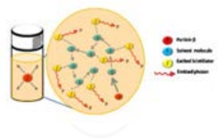
- Radioactive emissions cause solvent molecules surrounding the sample to become excited
- Excess energy from the solvent molecule is transferred to the fluor molecule
- Fluor contains phosphors which will scintillate when interacting with radiation
  - Often, secondary phosphors are included to help with detection
  - If the initial fluor wavelength is not able to be detected efficiently, the secondary fluor will absorb the energy and re-emit at a different wavelength



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LIQUID SCINTILLATION DETECTORS

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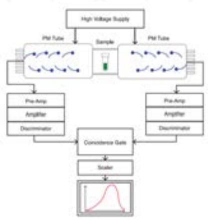
- Liquid scintillation detectors utilize coincidence counting
  - Scintillation vial is placed in a dark chamber with two photomultiplier tubes
  - The flash of light must be detected by both photomultiplier tubes to be "counted"
- Coincidence counting helps reduce the possibility of detecting background radiation
  - Especially important if trying to count a low activity sample
- This system maximizes the chance that the radioactivity will come in contact with the scintillator
  - Flash of light occurs just as with external scintillation detectors



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LIQUID SCINTILLATION DETECTORS

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- LSC is primarily used for alpha and beta emitting radiation
  - Particles which do not travel far enough to enter a typical crystal detector system
- Efficiency for alpha particles:
  - Close to 100% efficiency
- Efficiency for beta particles:
  - High energy (^{89}Sr, ^{90}Y):close to 100%
  - Low energy (^{14}C): approximately 95%
  - Low energy (^{3}H): 50 – 60%
- Its use in nuclear medicine / nuclear pharmacy applications is limited due to the types of isotopes we traditionally use
  - May see increased need if new therapeutic isotopes become more prevalent

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CONCLUSION

- A scintillation detector is a useful piece of equipment in a nuclear pharmacy, with some limitations
- Due to its ability to identify HOW MUCH and WHAT KIND of radioactive material is present
- Operator setup/use can greatly impact the output of this piece of equipment
- Any data obtained should be evaluated based on how the machine is operating

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Q1 - A

- At the beginning of this presentation, to what extent would you say that you are comfortable with how a scintillation detector works?
  - A. Extremely comfortable
  - B. I kinda know what I'm doing
  - C. I bet I learned it somewhere
  - D. Not a clue

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Q1 - B

- At the end of this presentation, to what extent would you say that you are comfortable with how a scintillation detector works?
  - A. Extremely comfortable
  - B. I kinda know what I'm doing
  - C. I bet I learned it somewhere
  - D. Not a clue

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Q2

- Scintillation detectors detect radiation that interacts with the detector by which mechanism?
  - A. Excitation
  - B. Ionization
  - C. Neither of these

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Q3

- What is the best detector for detecting alpha radiation?
  - A. GM survey meter
  - B. Single channel analyzer
  - C. Multi channel analyzer
  - D. Liquid scintillation detector

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