05 - Scintillation detectors

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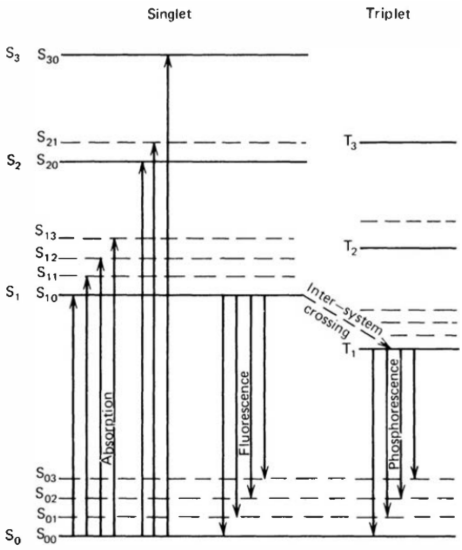
Version 2

Scintillation detector principles

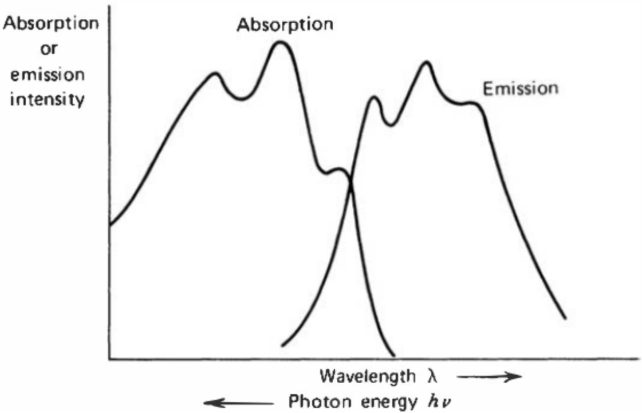
- Ionizing radiation detected by scintillation light
- Suitable scintillation material should follow some basic requirements
- Inorganic crystals (NaI)
- Organic liquids and plastic
- Fluorescence = emission of visible radiation after excitation
- Phosphorescence is emission with longer wavelength

Organic scintillators

- Fluorescence by transitions in a single molecule
- π-electron structure



Absorption and emission spectra of organic scintillator



Scintillation efficiency

- Fraction of energy of incident particle converted into visible light
- Quenching at impurities
- Transfer of excitation energy from molecule to molecule - binary scintillator
- Tertiary organic mixture with waveshifter

Pure organic crystals

- Anthracene - oldest organic scintillator
- Stilbene - fast response

Liquid organic solutions

- Organic scintillator in solvent (+ wavelength shifter)
- Large active volume $\sim$ meters
- Radiation resistant (no solid structure)
- Radioactive material may be present in the solution

Plastic scintillators

- Polymerized organic scintillator in solvent
- Arbitrary shape of final scintillator, large volume
- Radiation damage depends on nature of radiation
- May cause decrease of light output and/or decrease of light transparency

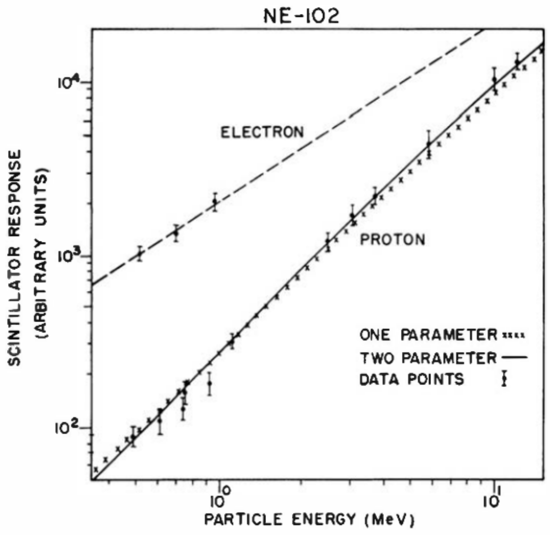
Thin film scintillators

- Very thin film of plastic scintillator, lower than range of weakly penetrating particles (heavy ions)
- Response as light yield per unit energy loss, depends on ion velocity and Z
- Transmission detector for protons and alpha, fast timing

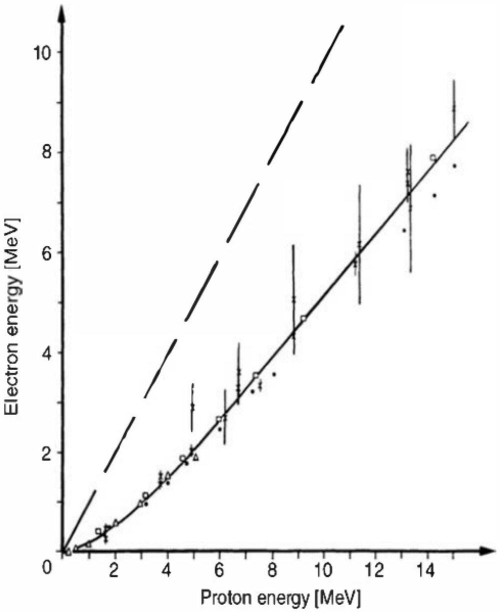
Loaded organic scintillators

- Direct detection of alpha and beta
- Addition of high-Z material to allow for photoelectric conversions
- Neutron detection with conversion elements

Light output of organic scintillator



Alpha-to-beta ratio



Absolute scintillation efficiency

- Normalization constant in relation between fluorescence energy and specific energy loss
- Variability among different materials
- Effect of radiation damage, surface crazing
- Degradation by long-term exposure to light and oxygen

Time response

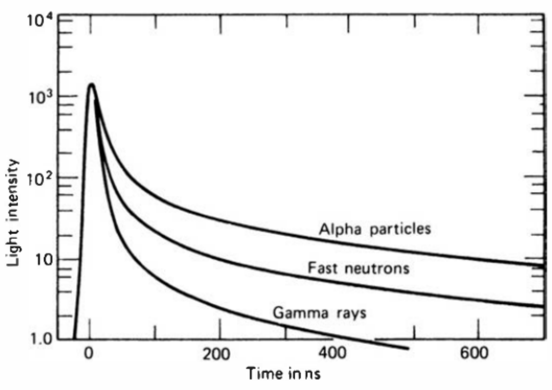
- Time to populate optical levels either exponential or Gaussian, followed by exponential decay

Table 8.2 Some Timing Properties of Fast Plastic Scintillators

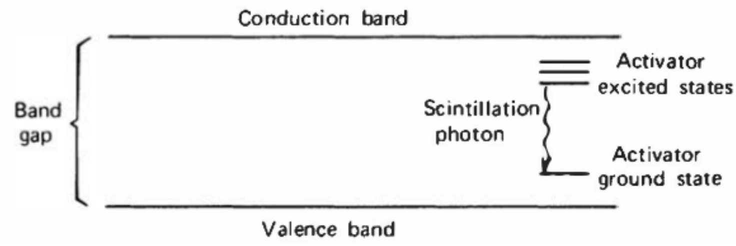
	Parameters for Eq. (8.10)		Parameters for Eq. (8.11)		
	τ_1 (rise)	τ (decay)	σ_{ET}	τ	Measured FWHM
NE 111	0.2 ns	1.7 ns	0.2 ns	1.7 ns	1.54 ns
Naton 136	0.4 ns	1.6 ns	0.5 ns	1.87 ns	2.3 ns
NE 102A	0.6 ns	2.4 ns	0.7 ns	2.4 ns	3.3 ns

Pulse shape discrimination in organic scintillators

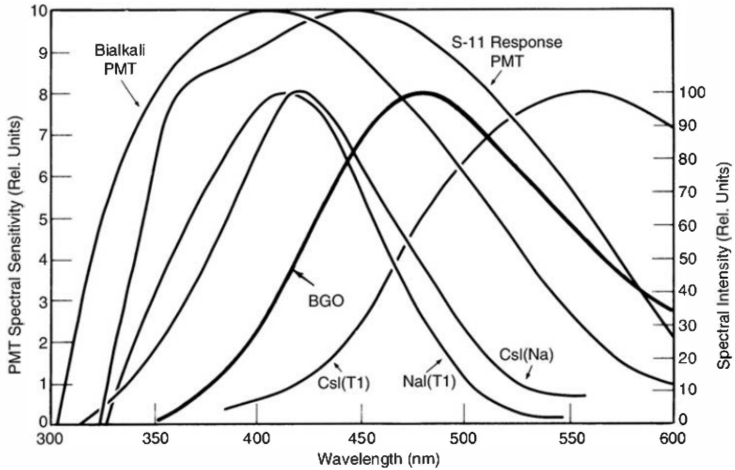
- Larger delayed constant for delayed fluorescence
- Depends on specific energy loss, allows for particle identification



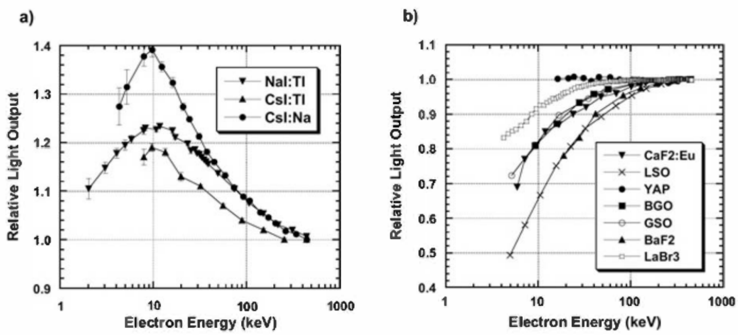
Inorganic scintillators



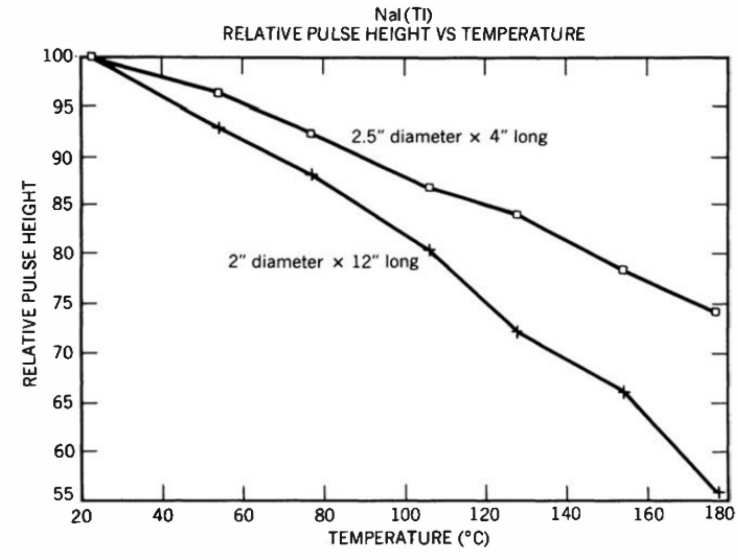
Emission spectrum of inorganic scintillators



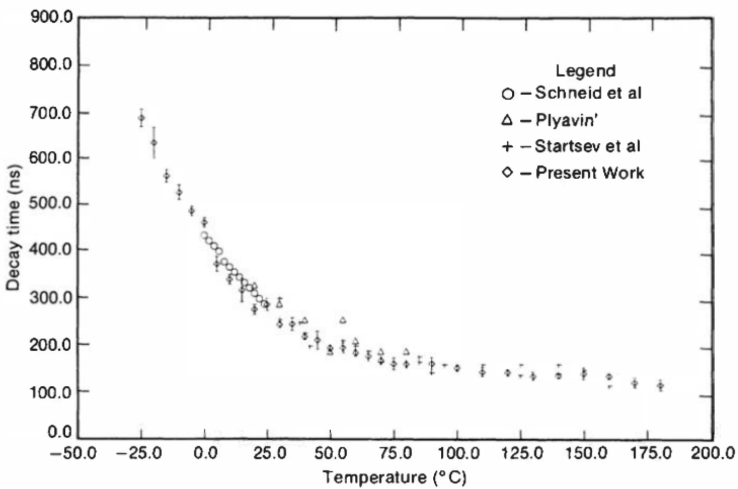
NaI(Tl)


a)
1.4
1.3
1.2
1.1
1.0
0.9
Relative Light Output
1
10
100
1000
Electron Energy (keV)
NaI:Tl
CsI:Tl
CsI:Na
b)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Relative Light Output
1
10
100
1000
Electron Energy (keV)
CaF2:Eu
LSO
YAP
BGO
GSO
BaF2
LaBr3

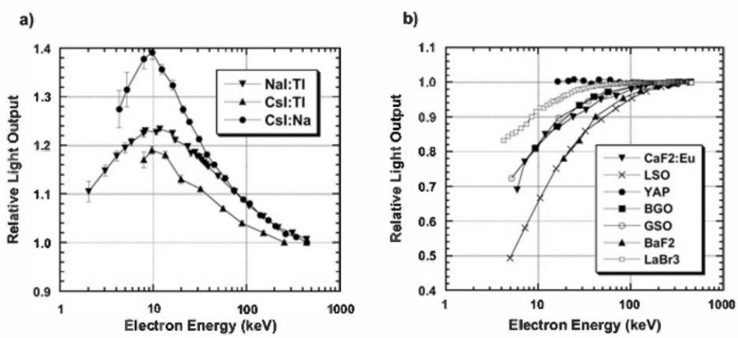
NaI(Tl) temperature dependence



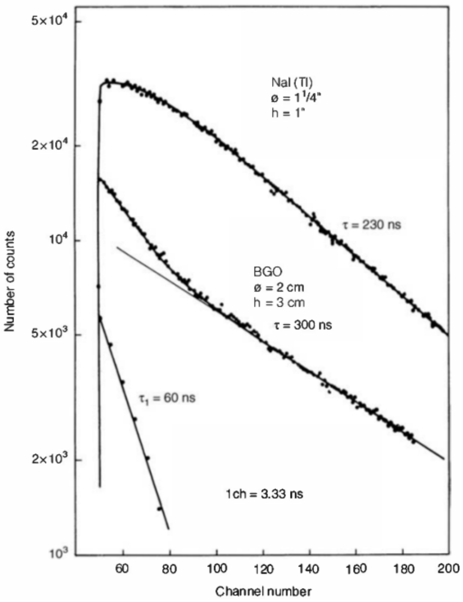
NaI(Tl) temperature dependence



CsI(Tl) and CsI(Na)



BGO

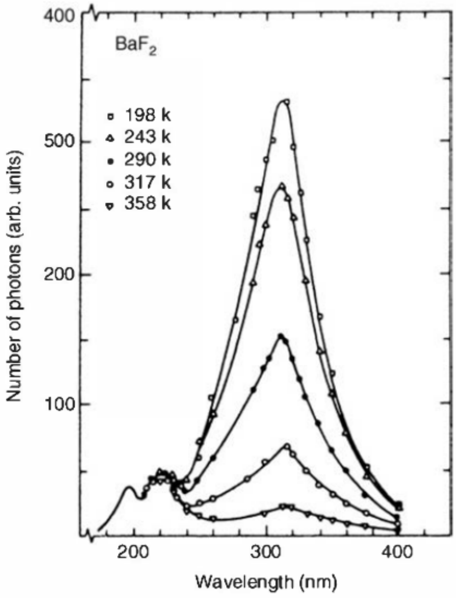


5×10⁴
2×10⁴
10⁴
5×10³
2×10³
10³
Number of counts
NaI (Tl)
ø = 1¹/4"
h = 1"
τ = 230 ns
BGO
ø = 2 cm
h = 3 cm
τ = 300 ns
τ₁ = 60 ns
1ch = 3.33 ns
60
80
100
120
140
160
180
200
Channel number

Other slow (>200 ns) inorganic crystals

- $CdWO_4$ and $CaWO_4$
- ZnS(Ag)
- CaF_2(Eu)
- SrI_2(Eu)

BaF_2

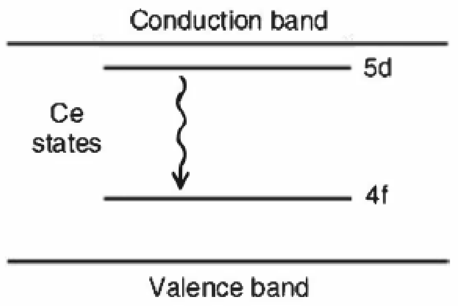


BaF2
198 k
243 k
290 k
317 k
358 k
Number of photons (arb. units)
400
500
200
100
200
300
400
Wavelength (nm)

Other unactivated fast inorganics

- CsI
- Cerium halides

Cerium activated fast inorganics



Transparent ceramic scintillators

- Nanocrystals in polycrystalline solid
- Used for X-ray tomography
- Allows for many combinations of materials and activators

Glass scintillators

- Silicate glass + Li + Ce activator
- Neutron detection
- Beta/gamma counting at severe environment
- Imaging application

Noble gas scintillators

- High purity gas as scintillation material, Xe, He
- Gas molecules excited by ionizing particle, UV scintillation light
- Arbitrary size and shape
- Linear response for specific energy loss measurement
- Secondary scintillation in proportional region with external electric field

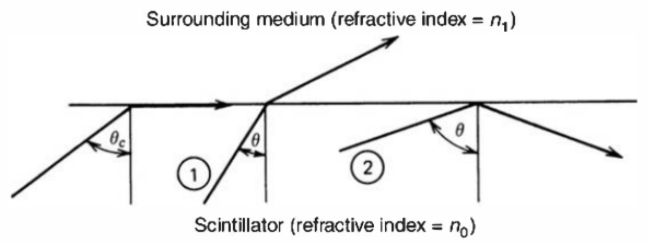
Cryogenic liquid and solid scintillators

- Liquid/solid Ar, Kr, Xe or He
- High scintillation efficiency, emission in UV region
- PM at cryogenic temperature

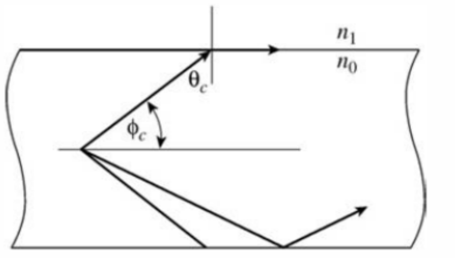
Radiation damage in inorganic scintillators

- Reduction of transparency
- Interference with scintillation mechanism
- Effects rate dependent
- Annealing at room temperature

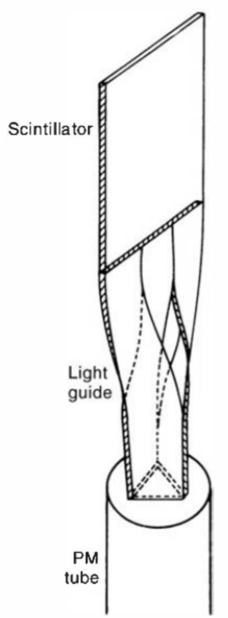
Light collection and scintillator mounting



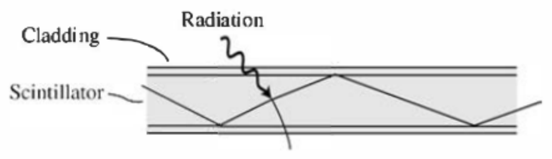
Light pipes



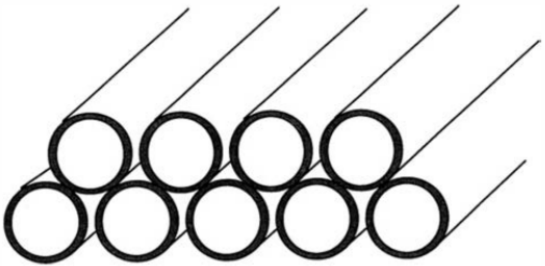
Strip light guide



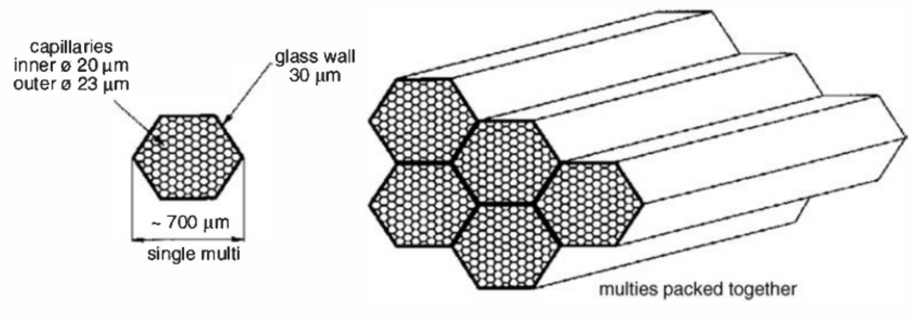
Fiber scintillators



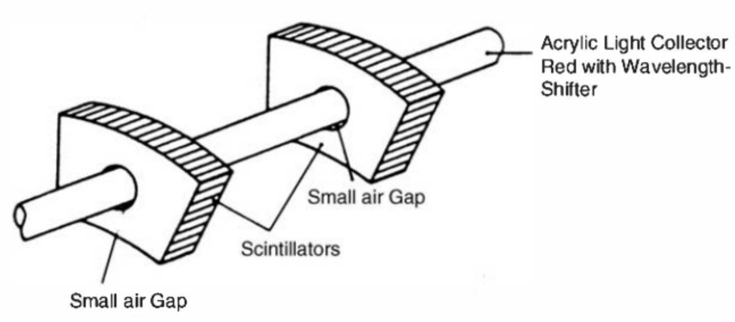
Ribbon array of fiber scintillators



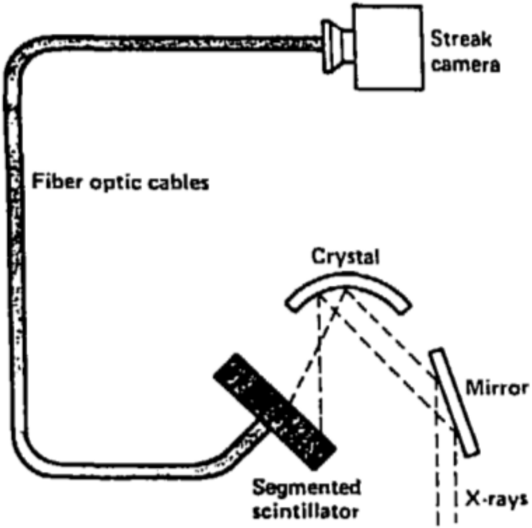
Glass capillaries in bundle



Wavelength shifters



Remote detection of X-rays



T. S. Perry and J. J. Molitoris, "Coupling between Plastic Scintillators and Light Fibers for Remote Detection of X-rays", Proc. SPIE 0566, Fiber Optic and Laser Sensors III, 218 (January 3, 1986)