^{3}He Replacement Technologies

(What ^{3}He is, why it's important, why we need to find a replacement)

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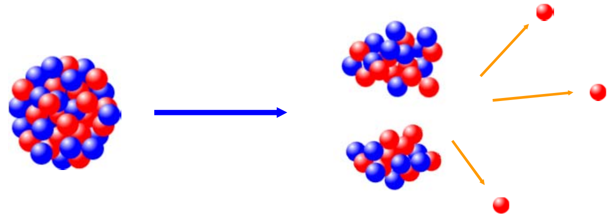
How do you detect plutonium?

Plutonium's strongest radiological signature is the emission of neutrons.



Neutrons are hard to detect – they're electrically neutral, so they don't interact with matter as much as other forms of radiation.

Need a detector material that's ***very*** good at capturing neutrons and delivering an electrical signal.

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Ideal Neutron Detector Material

1) Cheap!
2) High probability for capturing neutrons
3) Insensitive to other radiation types (gamma rays)
4) Easy to analyze (yields a strong, simple signal)
5) Safe (nontoxic, nonflammable, chemically inert)
6) Mechanically rugged
7) Thermally rugged

Gamma insensitivity is particularly important – many applications and environments have a lot of gamma rays. Don't want gamma rays giving false "neutron" signals.

This is a big problem for a lot of candidate neutron detector materials!

Cross Section

Neutron Detector Materials (1)

Helium-3 – $^{3}He(n,p)^{3}H$, ^{3}He is a noble gas
5300 barns
0.76 MeV final energy

Lithium-6 – $^{6}Li(n,^{4}He)^{3}H$, ^{6}Li in solid compounds
940 barns
4.78 MeV final energy

Boron-10 – $^{10}B(n,^{4}He)^{7}Li$, ^{10}B in solid compounds
3800 barns
2.3-2.8 MeV final energy

Neutron Detector Materials (2)

Gadolinium – 157Gd(n,158Gd*), Gd is a metal
254000 barns!!!
7-8 MeV final energy, but messy final state

Fission – Use U or Pu to capture neutrons (like a reactor)
Not really feasible if you want to *alarm* on U or Pu!

Fast recoil – Let fast neutrons collide (billiard balls) and detect recoil products
Feasible, but very non-traditional in our field!

^{3}He – Pretty Darn Good Neutron Detector

1) Cheap! (until recently $100 / liter)
2) High probability for capturing neutrons (5300 barns)
3) Insensitive to other radiation types (gamma rays)
   (*very* insensitive to gammas)
4) Easy to analyze (yields a strong, simple signal)
   (^{3}He proportional tubes very simple)
5) Safe (nontoxic, nonflammable, chemically inert)
   (helium is a noble gas – very safe)
6) Mechanically rugged
7) Thermally rugged
   (^{3}He proportional tubes mech. & therm. rugged)

The Saga of ^{3}He

- Tritium (^{3}H) is used in thermonuclear weapons. Tritium is radioactive (12.3 years), so the U.S. gvt (SRS) had a production program in order to maintain its weapons stockpile.
- When tritium undergoes radioactive decay, it creates ^{3}He. Tritium supply was regularly cleansed (SRS) to remove this ^{3}He.
- The ^{3}He was sold to industry, labs, etc. for various purposes, not least of which was neutron detectors. For decades ^{3}He was abundant and cheap – essentially the gvt subsidized its production and distribution.
- End of Cold War – reduction of weapons stockpiles, tritium program was ended. No more ^{3}He to be harvested.
- ^{3}He supply is vanishing!!!
  - $3000+ / liter, national labs, Obama

Applications That Use ^{3}He

- Safeguards.
  - Plutonium safeguards measurements impose very stringent requirements on the neutron detector – timing and gamma sensitivity. There really is no ^{3}He substitute.
- Assay Systems.
- Security Portals.
- Handhelds / Portables (minimal ^{3}He user; clever alternatives).
  - There are workable alternatives for these applications.

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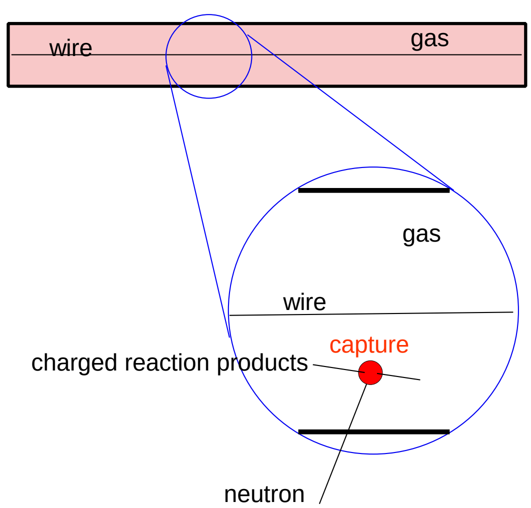
Gas Proportional Counters



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Gas Proportional Counters

with neutron-sensitive fill gas

- ^{3}He-filled tubes are the gold standard
  - For safeguards, there really is no ^{3}He substitute. Best strategy is conserve / redeploy ^{3}He where it's *really* needed.
- BF_3-filled tubes
  - Very similar in construction / operation to ^{3}He – familiar!
  - Roughly half as sensitive – need to redesign instruments.
  - It's cheap!!!
  - BF_3 is hazardous!!!
    - Still widely used / transported (CI uses it for detectors)
    - Explore risk-mitigation options (packaging, neutralizing gel, etc.)…possibly perception.
  - Likely a very good option for assay systems, maybe portals; could work for handhelds but there are likely better options.
  - The safety issue is a HUGE impediment to acceptance.

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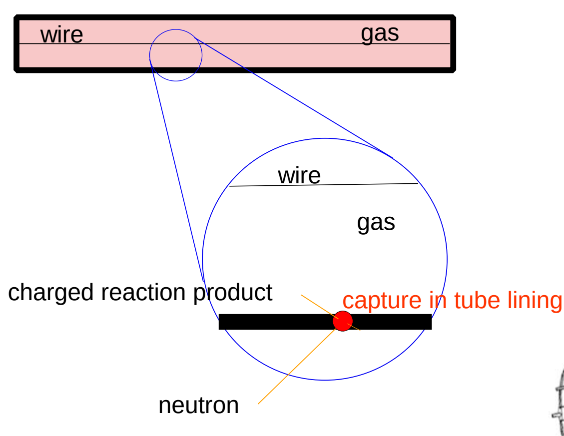
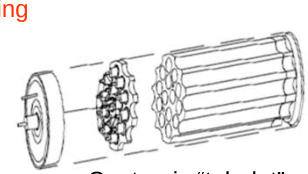
Lined Proportional Counters





Centronic "tubelet"

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Gas Proportional Counters

with neutron-sensitive liners

Make a “plain” proportional counter, use boron or lithium in a thin liner to capture neutrons and emit charged particles into the body of the tube.

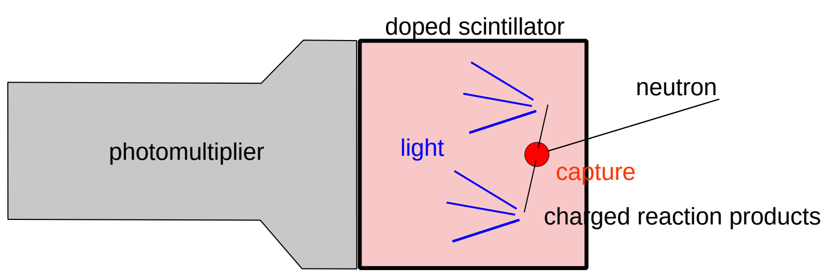
More expensive than BF_3, low sensitivity (~1/5 – 1/10) compared to ^3He.

Not really feasible for handhelds (needs too many tubes). Could be made to work for some systems and safeguards applications.

- GE / Reuter-Stokes – drop-in replacement panel for portals
- Centronic – modular 2” diameter drop-in tube replacement
- Proportional Technologies – boron-lined “straws”

Primary target is portal market – not as good as BF_3, but safe.

Doped Scintillator



Doped Transparent Scintillators

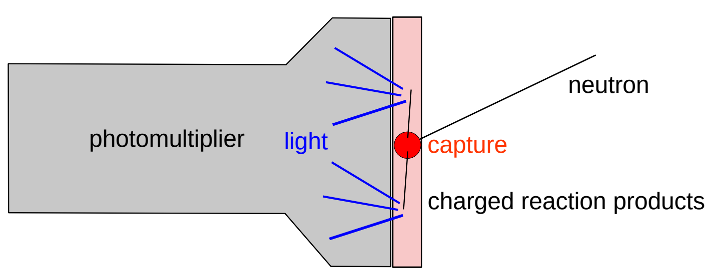
Mix boron or lithium compounds in with a transparent scintillator (plastic or glass). Use photomultiplier to collect light…similar to sodium iodide detector or the plastic slab in RadSentry.

HUGE and old (1950's) range of technology. Cheap! Easy!

Also quite gamma sensitive!

Not likely to be a solution for any of our applications.

Doped Opaque Scintillator



Doped Opaque Scintillators

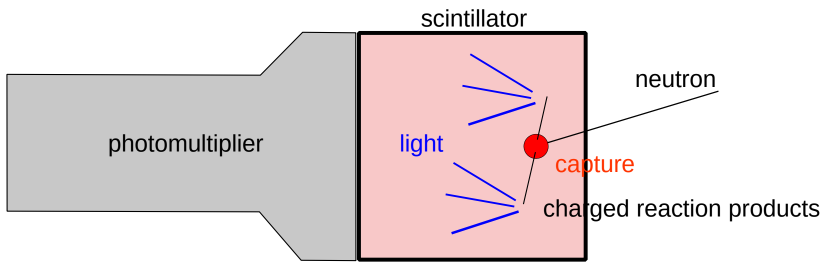
Mix boron or lithium compounds in with an opaque scintillator (ZnS) in very thin sheets. Use photomultiplier to collect light.

Old (1950's) range of technology. Cheap! Easy!

Very thin, so fairly immune to gammas.

Not likely to be a solution for assay systems or portals; quite possibly workable for handhelds.

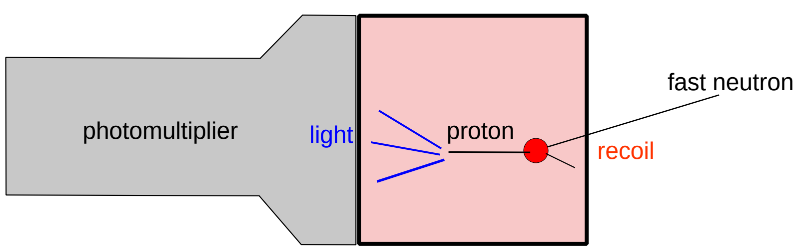
Neutron-sensitive Scintillator



Neutron-sensitive Scintillator Crystals

- ^{6}LiI crystals – Canberra doing some experimentation
  - Sensitive to gammas, but neutron capture peak appears at ~4.1 MeV gamma-equivalent energy, so it's easy to discriminate neutron events from gamma background.
  - Very likely suitable for handhelds, development ongoing
- "Exotic" crystals
  - "CLYC" CsLiYCl
  - "CLLC" CsLiLaCl Lithium provides neutron sensitivity
  - "CLLB" CsLiLaBr
  - Still in early-mid development stages (RMD); neutron sensitivity and gamma insensitivity still not well known; not much published.
  - CLYC is most widely known, neutron capture events at ~3.2 MeV gamma-equivalent energy.
  - Workable for handhelds…minor production issues.

Fast Neutron Recoil Scintillator



Fast Neutron Recoil

Fast neutrons collide with light elements (hydrogen) in a scintillating material. Recoiling products create light in scintillator. Use photomultiplier to collect light.

This is quite a different approach to neutron detection than is commonly used in our field. Would certainly require redesign of instruments, electronics, and probably software.

Old technology. Cheap! Gamma sensitive!

IAEA are claiming success with a liquid scintillator counter.

(liquid scintillators – volatile, flammable, leaky)

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Summary – what works where?

Technology	Safeguards	Systems	Portals	Handhelds
^{3}He proportional counters	***	***	***	***
BF_3 porportional counters		**		*
B-lined proportional ctr		**	**	
Doped transparent scint.				**
Doped opaque scint.				*
LiI (CI)				**
Exotic crystals (CLYC)				
Fast neutron recoil	* (?)	* (?)		

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