GE Oil & Gas – Reuter-Stokes

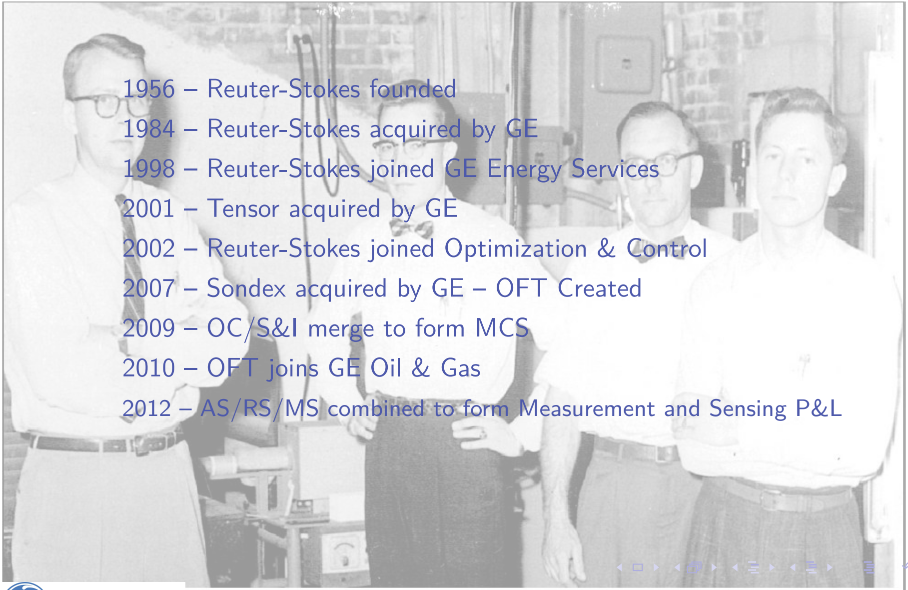
^{10}B and ^{10}B-Plus+® proportional counter

Mathieu Boucher

March 17, 2015

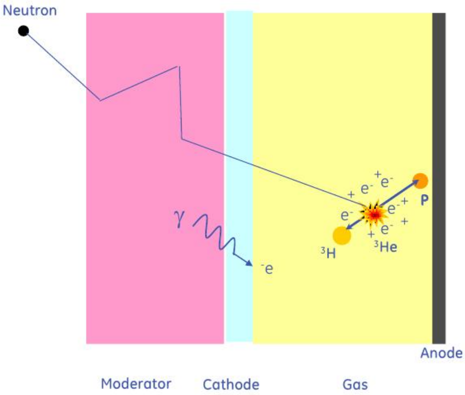
GE imagination at work

Reuter-Stokes key milestones



- 1956 – Reuter-Stokes founded
- 1984 – Reuter-Stokes acquired by GE
- 1998 – Reuter-Stokes joined GE Energy Services
- 2001 – Tensor acquired by GE
- 2002 – Reuter-Stokes joined Optimization & Control
- 2007 – Sondex acquired by GE – OFT Created
- 2009 – OC/S&I merge to form MCS
- 2010 – OFT joins GE Oil & Gas
- 2012 – AS/RS/MS combined to form Measurement and Sensing P&L

$^{3}_{2}$He Detector



$$^{3}_{2}He + ^{1}_{0}n \longrightarrow ^{3}_{1}H(0.191\,\text{MeV}) + ^{1}_{1}p(0.573\,\text{MeV})$$

$$\alpha = 5330\text{barns at } 0.025\,\text{eV}$$

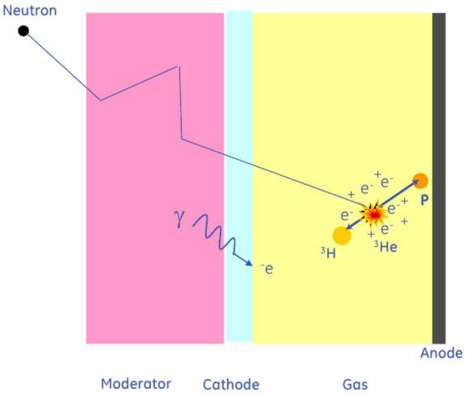
Detector: Construction

- Metallic outer housing
- Small diameter anode
- Proportional fill gas
- Welded and brazed construction
- Optimized ^{3}He pressure for desired efficiency
- Optimized size for instrument applications

Operation:

- Well understood principles
- Neutron captured by ^{3}He nucleus
- Gamma response primarily from interaction with detector wall
- Charge sensitive electronics
- Well defined spectrum

$^{3}_{2}$He Detector



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International Shortage of Helium-3 Mitigated

NIDC: Newsletters

www.isotopes.gov/news/newsletters.html

Notices

March 2014: International Shortage of Helium-3 Mitigated
Notice #27 March 12, 2014

Helium-3 (He-3) is a stable isotope supplied mainly by artificial operations. The sole source of domestic He-3 is from the decay of radioactive tritium produced for the Department of Energy's (DOE) nuclear weapons stockpile. The He-3 gas is separated from tritium located at the National Nuclear Security Administration's (NNSA) Savannah River Site (SRS). As the designated office for isotope production and distribution, the Office of Nuclear Physics Isotope Program in DOE's Office of Science administers He-3 extraction and distribution.

As the Department's excess He-3 became available in the past 60 years, it has been widely used in government and commercial applications including medical diagnostics, cryogenics, basic and applied materials research, and neutron detection and measurement applications including research, oil and gas exploration, and highway construction. Demand increased dramatically in the past decade owing to expanded use of He-3 gas in neutron detectors for national security, nonproliferation, defense, border security, and homeland security.

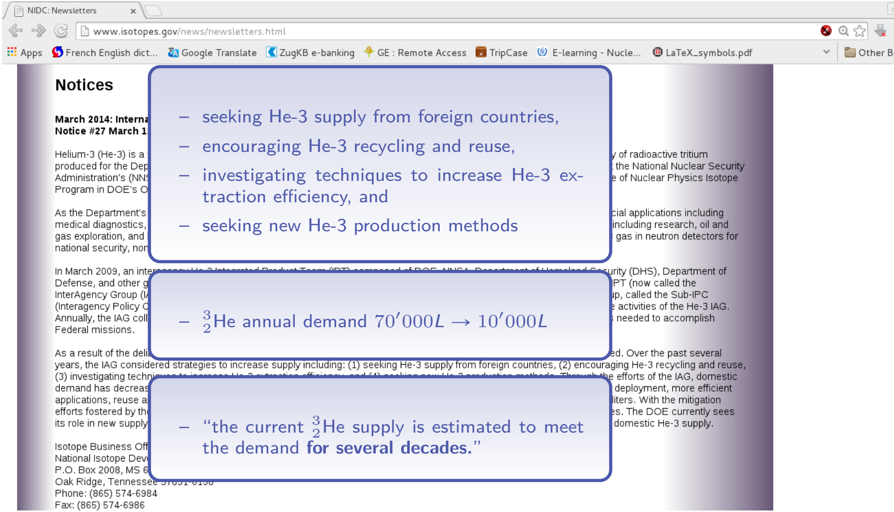
In March 2009, an interagency He-3 Integrated Product Team (IPT) composed of DOE, NNSA, Department of Homeland Security (DHS), Department of Defense, and other government agencies was formed to address decreasing supply of and increasing demand for He-3. The IPT (now called the InterAgency Group (IAG) with representation from fourteen different federal agencies) reports to a higher level interagency group, called the Sub-IPC (Interagency Policy Committee), chaired by the National Security Council. The Director of the DOE Isotope Program chairs the activities of the He-3 IAG. Annually, the IAG collects He-3 demand information from the Federal complex, identifying and scrutinizing the requests for gas needed to accomplish Federal missions.

As a result of the deliberations of the IAG and close interagency coordination, impacts of the 2008 shortage have been alleviated. Over the past several years, the IAG considered strategies to increase supply including: (1) seeking He-3 supply from foreign countries, (2) encouraging He-3 recycling and reuse, (3) investigating techniques to increase He-3 extraction efficiency, and (4) seeking new He-3 production methods. Through the efforts of the IAG, domestic demand has decreased dramatically by a combination of actions including prioritization, alternative technologies research and deployment, more efficient applications, reuse and recycling; federal demand has decreased from an annual demand of 70,000 liters to less than 10,000 liters. With the mitigation efforts fostered by the He-3 IAG, the current He-3 supply is estimated to meet the federal domestic demand for several decades. The DOE currently sees its role in new supply as a facilitating role, and is having discussions with industry to see how it can help industry in increasing domestic He-3 supply.

Isotope Business Office
National Isotope Development Center
P.O. Box 2008, MS 6158
Oak Ridge, Tennessee 37831-6158
Phone: (865) 574-6984
Fax: (865) 574-6986

http://www.isotopes.gov/news/newsletters.html

International Shortage of Helium-3 Mitigated



- seeking He-3 supply from foreign countries,
- encouraging He-3 recycling and reuse,
- investigating techniques to increase He-3 extraction efficiency, and
- seeking new He-3 production methods

- ${}^{3}_{2}$He annual demand $70'000L \rightarrow 10'000L$

- "the current ${}^{3}_{2}$He supply is estimated to meet the demand **for several decades.**"

http://www.isotopes.gov/news/newsletters.html

Radiation Measurement Solutions

50 Years of Experience

- Over 10,000 neutron counter designs manufactured
- ^{3}He gas-filled detectors – multiple designs
- ^{10}B lined detectors – reactor power monitoring
- BF_3 gas-filled detectors
- High pressure ion chamber
- Scintillator packaging for harsh environments (O&G)
- ^{3}He recovery and purification

Core Competencies

- Harsh Environment Packaging
- Handling Sensitive Materials
- Radiation Detection
- Precision Fabrication
- Product Testing & Modeling

RS Skills

- Brazing, welding
- Long lived
- Integrated electronics

- Radioactive Sources
- Hygroscopic materials
- NRC compliance / DOT shipping regulations

- neutron
- γ radiation
- Ultraviolet

- Thin metal welding
- Coatings – electroplating and boron
- thin wire and cable processing

- Environmental testing
- Position calibration
- Monte Carlo simulation

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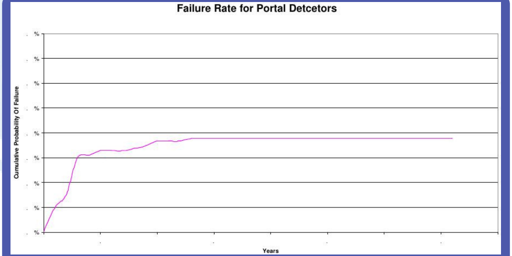
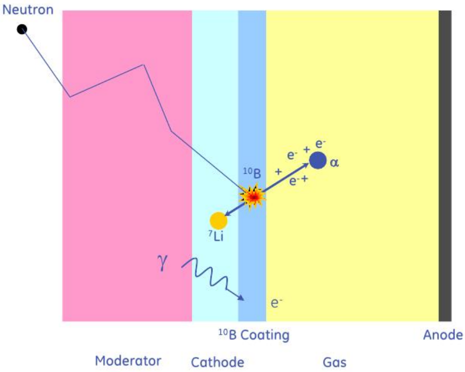


MTBF: 832 years

GE imagination at work

${}^{10}_{5}$B Detector



$$n + {}^{10}B \rightarrow \alpha + {}^{7}Li (4\%)$$

$$n + {}^{10}B \rightarrow \alpha + {}^{7}Li^{*} (96\%) + 0.49\,\text{MeV}$$

$$\sigma = 3840\text{barns} \ @ \ 0.025\,\text{eV}$$

Detector: Construction similar to ^{3}He

- Metallic outer housing
- Small diameter anode
- Proportional fill gas
- Welded and brazed construction

${}^{10}_{5}$B Lining: organic formulation

- Thin layer on internal shell
- Optimize coating thickness
- Use boron enriched in ${}^{10}_{5}$B isotope

Operation: new design

- Same physics principles
- Charge sensitive electonics
- Well defined spectrum
- Validated through use in nuclear reactor instrumentation

GE imagination at work

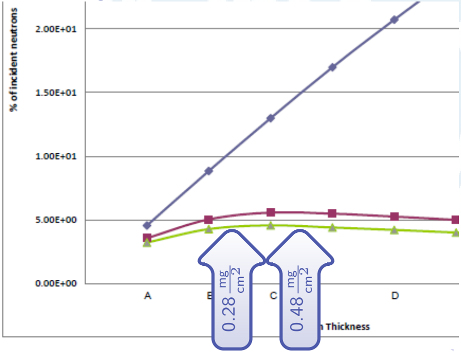
$^{10}_{5}$B Detector

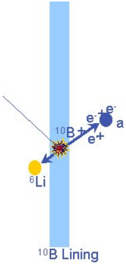
$^{10}_{5}$B Coating Optimization

Thickness: optimize neutron counting

Too thin: fewer neutron reactions/higher probability of reaction products escaping into detector volume

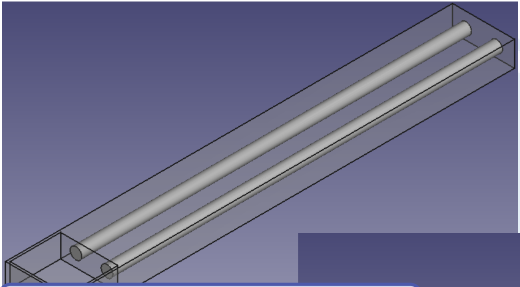
Too thick: more neutron reactions/reaction products absorbed in lining



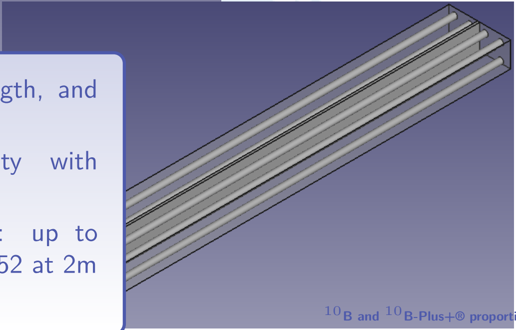


^{10}B Neutron Detection Modules

$^{3}_{2}$He NDM



$^{10}_{5}$B NDM



- Variable width, length, and height of RPM
- Increased sensitivity with longer B-10 tubes
- Variable sensitivity: up to **4.5cps** per ng Cf-252 at 2m

GE imagination at work

GERS ^{10}B NDM Testing

Temperature Testing

- ↦ From 55°C to -40°C at a rate of 10°C/hour

⟹ No change in count rate was observed beyond statistical fluctuations.

Vibration Testing

- ↦ ANSI vibrations testing = 0.5g level in x and y axis
- ↦ GERS = 2.5g level applied to the NDM in x and y axis
- ↦ Additional z-axis vibration testing = 2.5g level
- ↦ high voltage applied

⟹ No spurious counts or detector breakdowns were observed.

Nuclear Testing

Criterion	Required	Achieved
η_n (cps/ng-252 Cf)	>2.5	up to 4.5
$\epsilon_{int,\gamma}$	1.00×10^{-6}	5.5×10^{-9}
$\frac{\epsilon_\gamma}{\epsilon_n}$	0.001	0.000004
GARRn	0.9 < GARRn < 1.1	1.01

Additional testing with γ field up to 1Sv/hr

GE imagination at work

GERS B-10 Timeline

Feb 2010 – Technology feasibility demonstrated

Sep 2010 – Independent third party testing completed
Multiagency test

Dec 2010 – Product commercialized – initial low rate production

Nov 2010 – DNDO qualification program
environmental / vibration / EHS / nuclear / field
>7,000 occupants $\Rightarrow$ ^{10}B NDM = ^{3}He NDM
Active Cargo Imaging

Dec 2010 – First modules shipped for use in DoD RPMs

Jan 2012 – DNDO validation

2012 – National Labs: mobile system
$\Rightarrow$ satisfactory

False alarms – Gamma rejection slightly better than ^{3}He detectors

Safeguards Applications

- Large variety of coincidence counters used for safeguards applications
- Four common coincidence counters:[**PANDA**, **1991**]
  - Underwater coincidence counter (UWCC)

    The UWCC is used for underwater verification of Pu in fresh MOX fuel assemblies.
  - Active well coincidence counter (AWCC)

    The AWCC is used for verification of 235U in highly enriched U samples.
  - High-level neutron coincidence counter (HLNCC)

    The HLNC is used for verification of Pu in 20–2000 g canned samples.
  - Uranium neutron coincidence collar (UNCL)

    The UNCL is used for verification of ^{235}U in low enriched U fuel assemblies.

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    The UNCL is used for verification of ^{235}U in low enriched U fuel assemblies.

Safeguards Applications

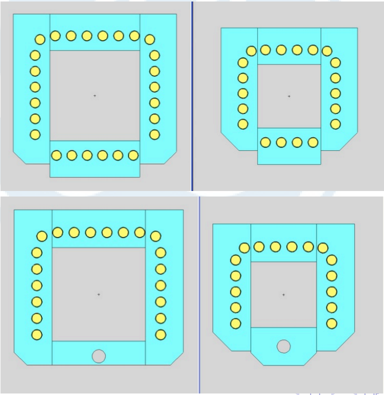
UNCL

- **Passive mode**: Measurement of Pu in MOX fuel
- **Active mode**: Verification of ^{235}U in low enriched U fuel assemblies
- Measurement $\sigma < 1\%$ in ~ 15 minutes

Modeling

Passive $^{3}_{2}$He based UNCL

Active $^{3}_{2}$He based UNCL



PWR BWR

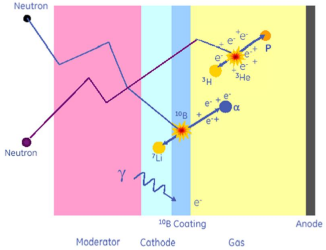
[Kouzes, 2013]

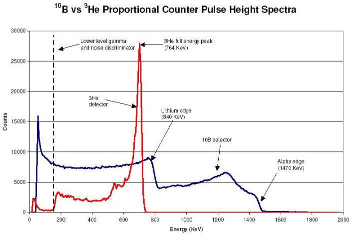
B10Plus+® Neutron Detector

How does it work?

B10Plus+® is :

GE ${}^{10}_{5}$B lined proportional counter incorporates a small amount of ${}^{3}_{2}$He = boost neutron sensitivity





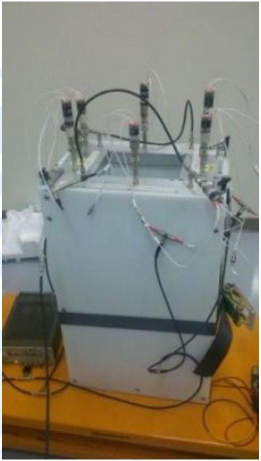
GE imagination at work

Neutron Coincidence Counter

${}^{10}_{5}$B ABUNCL

GE Reuter Stokes built a prototype ABUNCL

- ↳ with seventy-two (72) 1-inch diameter ${}^{10}_{5}$B lined proportional counters, and
- ↳ with cavity dimensions configured for BWR fuel rod bundles ($16.5cm \times 23.4cm$).



UNCL-1 [Canberra]

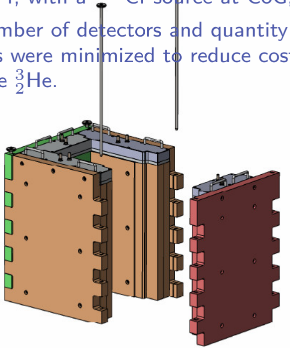
Canberra UNCL in passive mode.

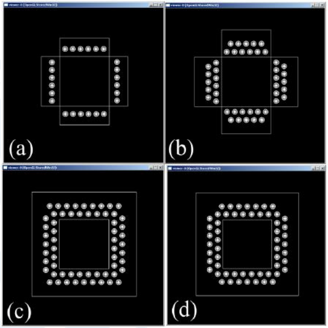
- ↳ with twnety four (24) 1-inch diameter ${}^{3}_{2}$He proportional counters, and
- ↳ with cavity dimensions configured for BWR fuel rod bundles ($16.5cm \times 23.4cm$).

Neutron Coincidence Counter

B10Plus+® UNCL-1

- Four footprints were considered,
- Cavity dimensions configured for PWR fuel rod bundles ($23.4cm \times 23.4cm$).
- 85 configurations were simulated using GEANT4, with a ^{252}Cf source at CoG,
- The number of detectors and quantity of $^{3}_{2}$He gas were minimized to reduce cost and conserve $^{3}_{2}$He.





(a) existing UNCL-1 design.

(b) based on the UNCL-1, with up to 2 additional rows of detectors.

(c) and (d) are designed to maximize the number of detectors nearest the cavity.

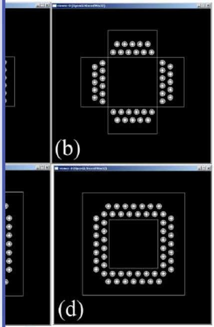
Neu

Variables in GEANT4 simulations

- Detector diameter
  - ↳ 25 mm – 28.6 mm
  - ↳ **25mm**
- Moderator thickness
  - ↳ 9 mm – 14 mm
  - ↳ **14mm**
- Thickness of moderator in front of first row
  - ↳ 6.35 mm – 19.1 mm
  - ↳ **12.7mm**
- Thickness of moderator between rows
  - ↳ 6.35 mm – 12.7 mm
  - ↳ **12.7mm**
- Active length
  - ↳ 14 inch – 24 inch
  - ↳ **18 inch**
- $^{3}_{2}$He partial pressure
  - ↳ 0 atm – 1 atm
  - ↳ 0.5 atm (inner row), 0.25 atm (outer row), 4.9 liters total
- $^{10}_{5}$B coating loading
  - ↳ 0.1 mg/cm^2 – 0.55 mg/cm^2
  - ↳ **0.24 mg/cm^2**

B

- Fo
- Ca ro
- 85 GE
- Th $^{3}_{2}$H co



UNCL-1 design.

on the UNCL-1, with dditional rows of de-

are designed to max- number of detectors cavity.

GE imagination at work

Figure of Merit

$$\text{FoM} := \frac{\varepsilon^2}{\tau}$$

where:

FoM: Figure-of-Merit
↳ optimizes system performance
ε: detection efficiency
τ: die-away time
↳ measures of how long the neutron takes to slow down (thermalize) and be captured

	$^3_2$He (liters)	ε (%)	τ (μsec)	FoM
UNCL-1[1]	16	13.07	52.2	3.27
$^{10}_{5}$B ABUNCL (at GERS)	–	12.1	65.6	2.23
PNNL[2]	–	11.6	75.2	1.79
GEHCC[3] (model)	4.9	16.9	84.1	3.40
GEHCC (measured)	4.9	16.96 ± 0.37	84.9 ± 6.0	3.39 ± 0.28

[1] **[Canberra]**
[2] **[Kouzes, 2012]**
[3] B10Plus+® UNCL-1

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Within $\sigma \pm 5\%$ source strength

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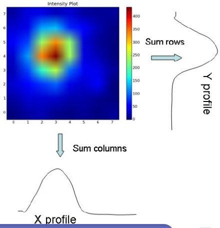
Neutron Scattering

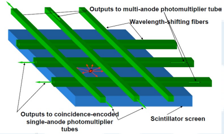
Anger Camera

Light cone



- Resolution: $< 1.2mm$;
- Sensitive to high γ background
- Small area covered: $15cm \times 15cm$
- Efficiency: $> 90\%$ for neutrons at $4A$
- Count rate: $50'000cps$ with 15% deadtime
- Count rate uniformity: $\pm 4\%$

WLS



- Resolution: 5mm $\times$ 5.8mm
- Sensitive to high γ background
- Small area covered: 0.3m^2
- Relatively high efficiency: 60% @ 1Å
- μs time resolution

Next Gen. Electronics

- Vacuum handling;
- Power over Ethernet (PoE):
- Precision Time Protocol with sub μs accuracy / resolution
- Modular front-end with high speed ADC
- Modular High Voltage supply
- Embedded Linux on dual core ARM-A9 processor
- High performance Programmable Logic/DSP resources

GE imagination at work

Further Reading

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