Requirements on Neutron Detectors Alternative to He-3

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Neutron Detector Technologies Workshop in Vienna
(22 – 24 March 2011)

IAEA short term needs for existing installed SG instrumentation

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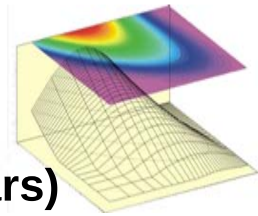
Outline

- Fraunhofer INT (spheres of work)
- Irradiation Facilities at INT
- Earlier work performed for IAEA: Qualification of ^{3}He detectors
- Concepts for ^{3}He replacement: advantages and drawbacks
- Conclusion

Fraunhofer Institute for Technological Trend Analysis INT
(Fraunhofer Institut für naturwissenschaftlich-technische Trendanalysen)



- **100 Staff (75 Man Years)**
  including
- **45 Scientists**
- **Budget ~7.2 Mio €**
  including
  ~3,2 Mio € Contract Research

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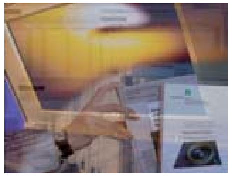
The Business Areas of INT



Trends and Developments in Research and Technology

Planning, Programs and Structures in R&T

Nuclear Effects, Threats and Detection Systems

Electromagnetic Effects and Threats

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Electromagnetic Effects and Threats

NEMP - Origin and Propagation; Modeling and Simulation

Effects of Pulsed High Power Microwaves (HPM)

EMC, HPM and NEMP Measurement

Management of Simulation and Measurement Equipment for Electromagnetic Fields

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Nuclear Effects, Threats and Detection Systems

Nuclear Security Policy and Detection Techniques

assessment of physical and technological aspects of nuclear threat and security

Nuclear Radiation Detection and Identification in the Field

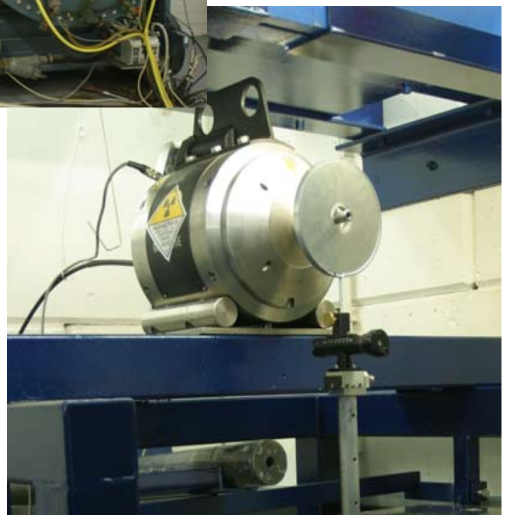
Nuclear Radiation Effects in Electronics and Optoelectronics

Radiation Effects in Fiber Optic and Electronic Systems

Nuclear Effects, Threats and Detection Systems

Highlight **Nuclear Radiation Effects in Electronics and Optoelectronics**

X-ray flash machine
Febetron 705



Gamma-Irradiation Facility
TK 1000

Analysis of the Effects of Ionizing Radiation on Electronic and Optical Components, esp. on Fiber Optic Systems

Management of irradiation facilities for Gamma, Electron, Proton and Neutron Radiation

Qualification of Components and Systems

Identification of Radiation Hard Products

Development of New Sensors for Nuclear Radiation

Advice to Producers and Users of Fiber Optic Systems (Space, High Energy Accelerators, Nuclear Technology Environments and Medicine).

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Nuclear Effects, Threats and Detection Systems

Highlight **„Nuclear Security Policy and Detection Techniques“**

Mobile measuring systems for non-destructive and non-contact detection as well as identification of radioactive or special nuclear material on site.

- Nuclear Security Policy, non-proliferation and arms control, Safeguards
- Non-destructive detection and verification of radioactive material as well as fissile material (appropriate for nuclear weapons) on site (surveying cabin NANU)
- Measuring car DeGeN – Detection of Gammas inclusive Neutrons, search and identification of radioactive and nuclear material
- Systems for verification of radioactive and nuclear material, including active interrogation with neutrons by a portable neutron generator and development of mobile neutron radiography

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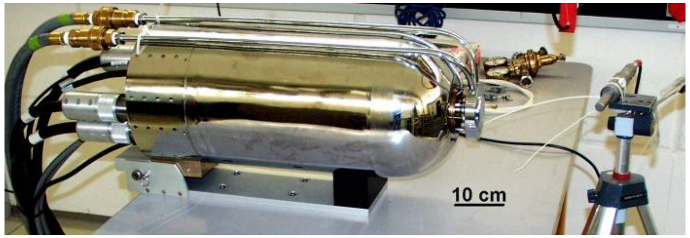
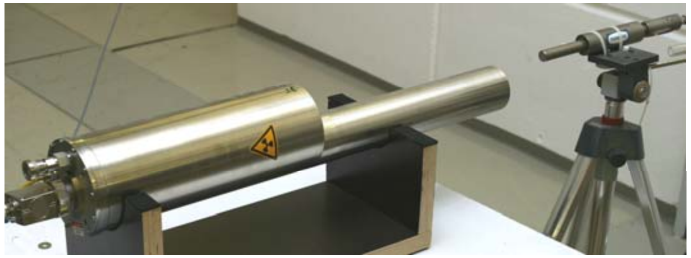
Available irradiation facilities at INT

- several intense Co-60 sources up to 19 TBq (→ 4.5 Gy/h in 1 m)
- several neutron generators
  - Thermo D-711 (DD & DT)
  - Sodern Genie 16C (DD & DT)
- Flash X-Ray and Electron Febetron 705
- Large variety of isotopic sources
  - Th-228 , U-238, Am-241, Cm-244
  - H-3, C-14, Cl-36, Sr-90, Pm-147, Tl-204
  - Na-22, Mn-54, Co-60, Ba-133, Cs-137, Eu-152+Eu-154+Eu-155
  - Cf-252, Am/Be, Am/Li





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Qualification of ^{3}He-tubes „RS-P4-0812-115“and „RS-P4-0808-212“

Performed under the German Support Program (GSP)

Joint Program on the
Technical Development and Further Improvement of IAEA Safeguards

Determination of an Optimized Polyethylene Moderator for He-3 Neutron Detectors

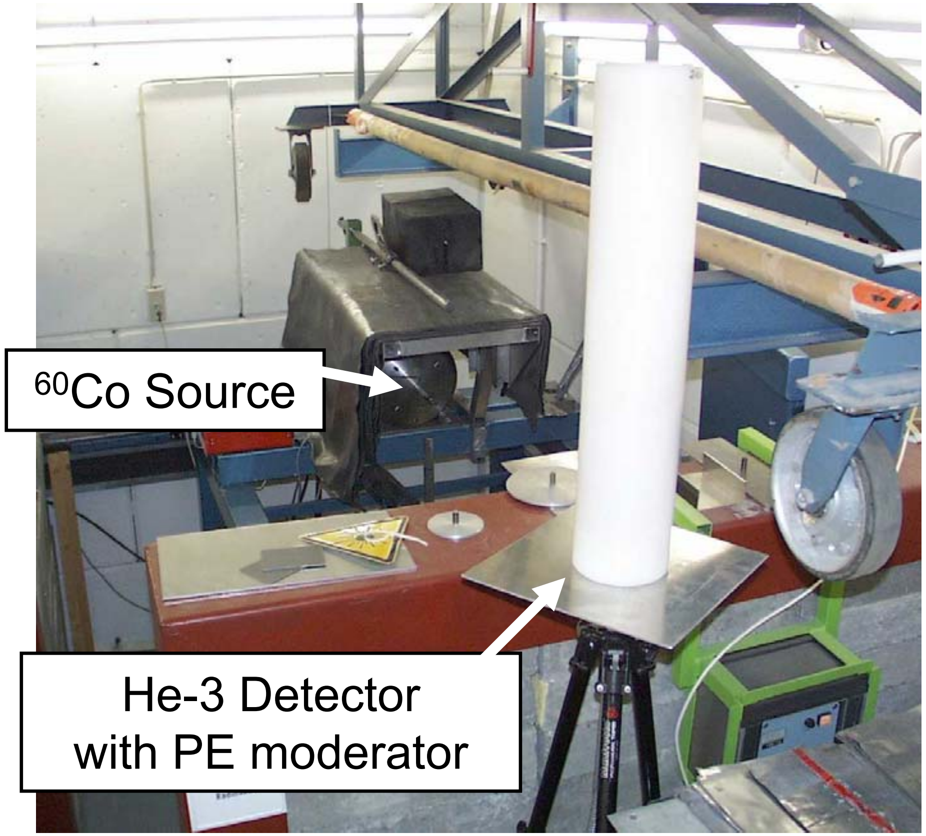
RS-P4-0812-115

- 401.3mm x 26.2mm dia
- Body: aluminum 1100-F
- 4.2 bar He-3
- 1500 V HV
- Surrounded with 50 mm PE

RS-P4-0808-212

- 303.0mm x 26.2mm dia
- Body: stainless steel 304
- 4.1 bar He-3
- 1750 V HV
- Surrounded with 50 mm PE

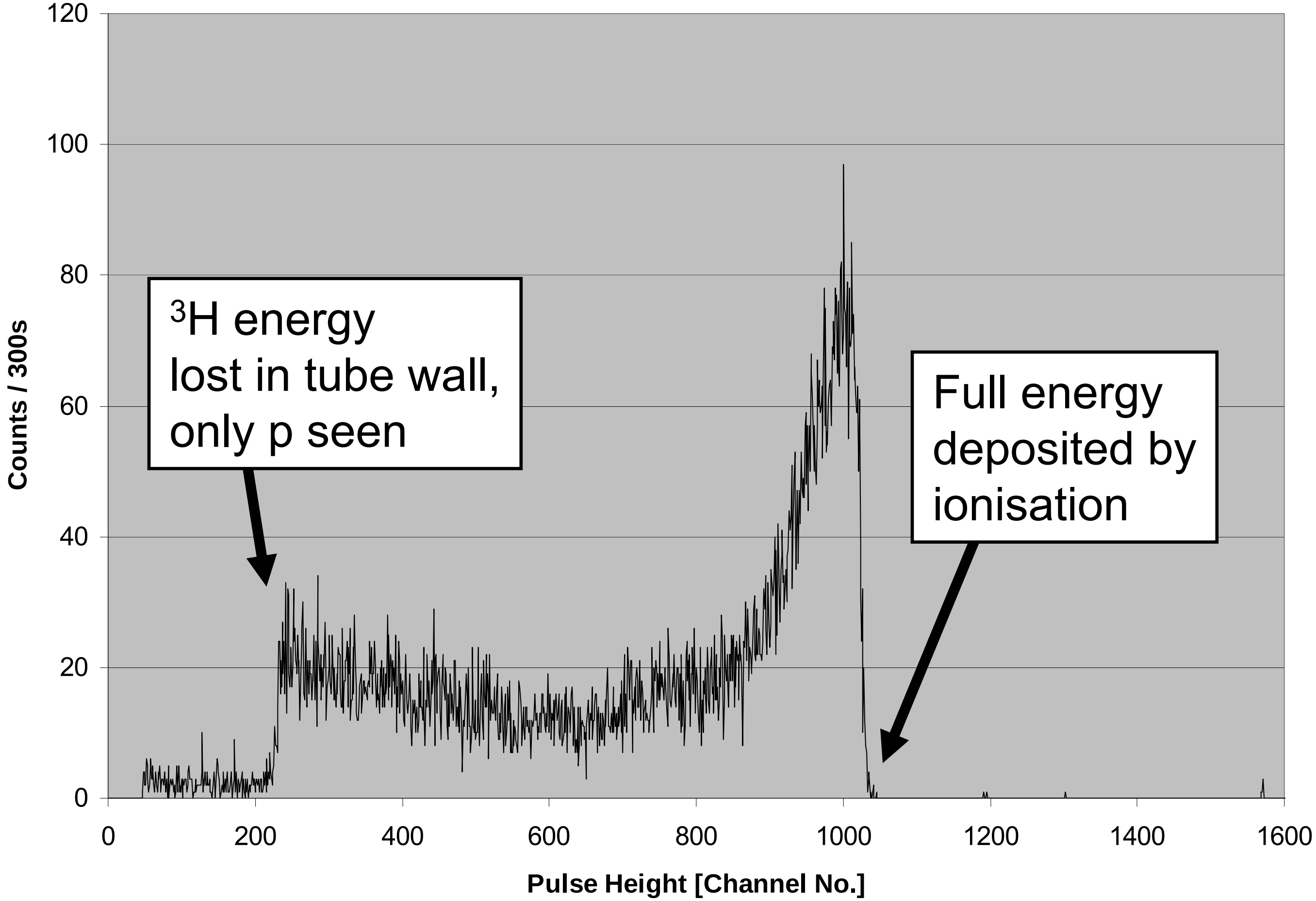
Experimental Setup: Evaluation of Gamma Sensitivity



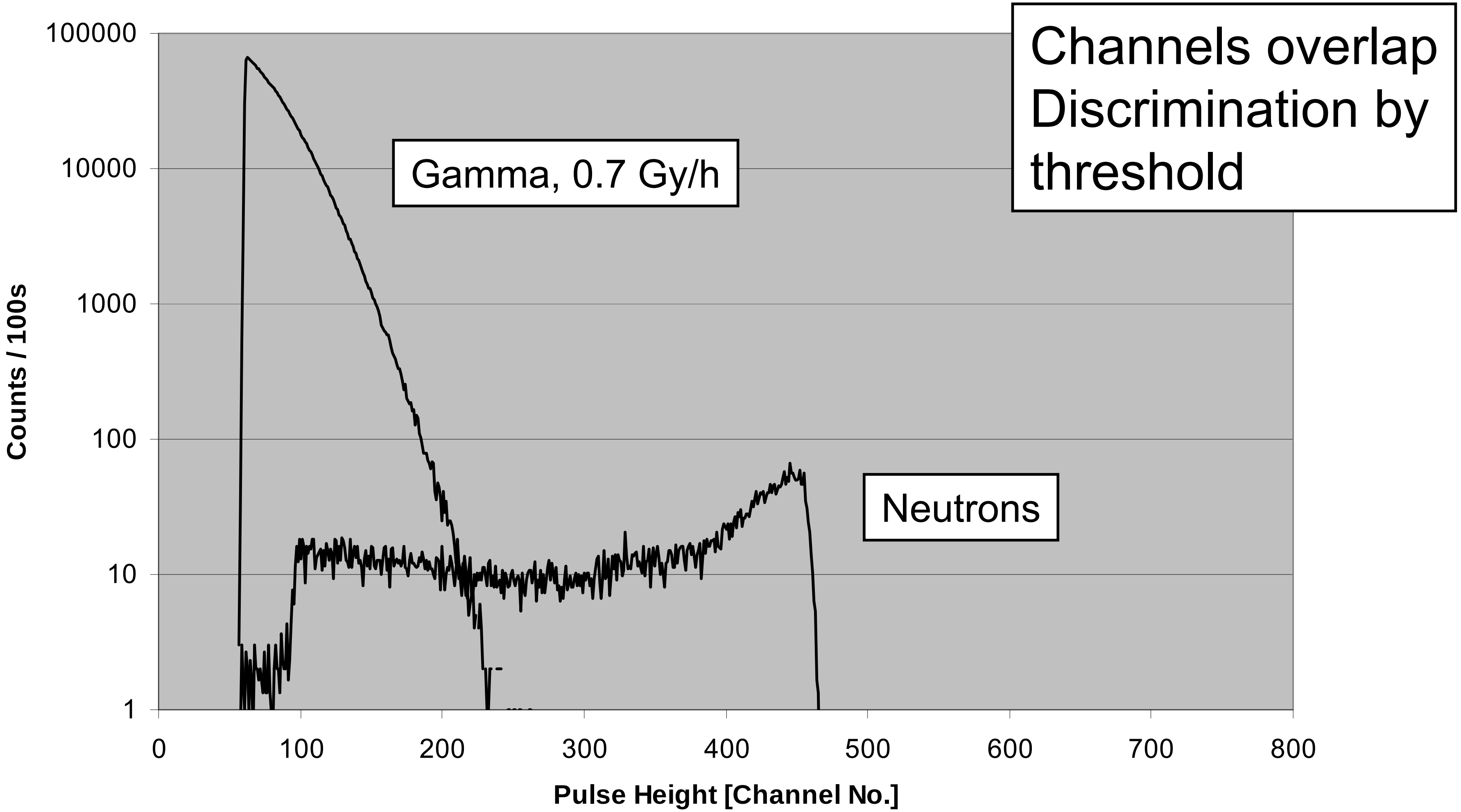
- Co-60 source
  - Activity: 17.2 TBq
  - Different distances to vary flux
- Cf-252
  - Activity: 1.4 MBq
  - Emission: 1.5 10^5 n/s in 4π
  - Placed 1.3 m from He-3 tube
  - Flux: 0.75 n/(cm^2 · s)
- PNPI Electronics
  - Preamplifier, shaping amplifier and threshold
  - Threshold from 0 to 1.2 V

Neutron Pulse Hight Spectrum of He-3 Tube

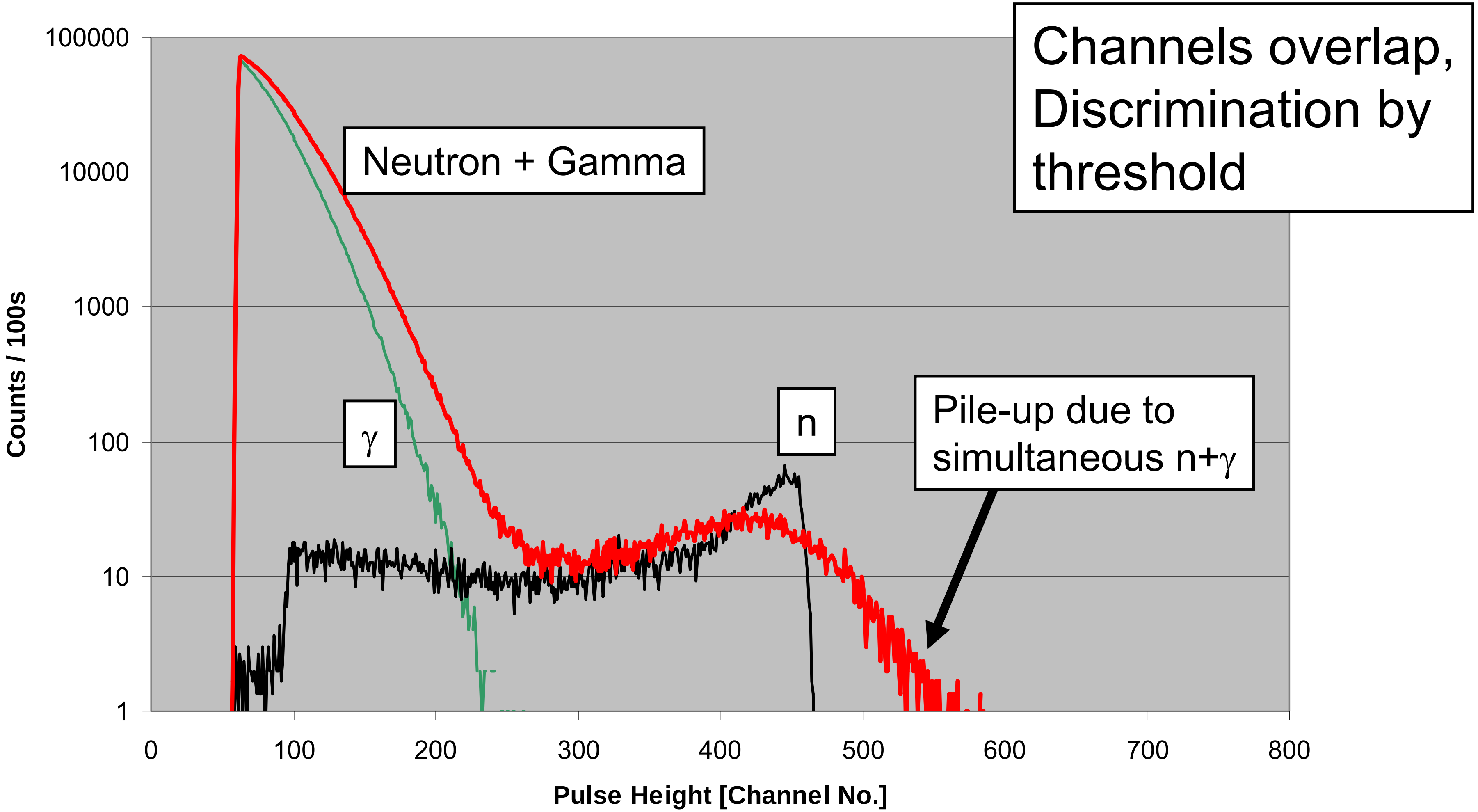
$$n + {}^{3}He \rightarrow {}^{3}H + p + 764\ keV$$



Comparison of Neutron / Gamma only spectrum



Combined Neutron / Gamma spectra



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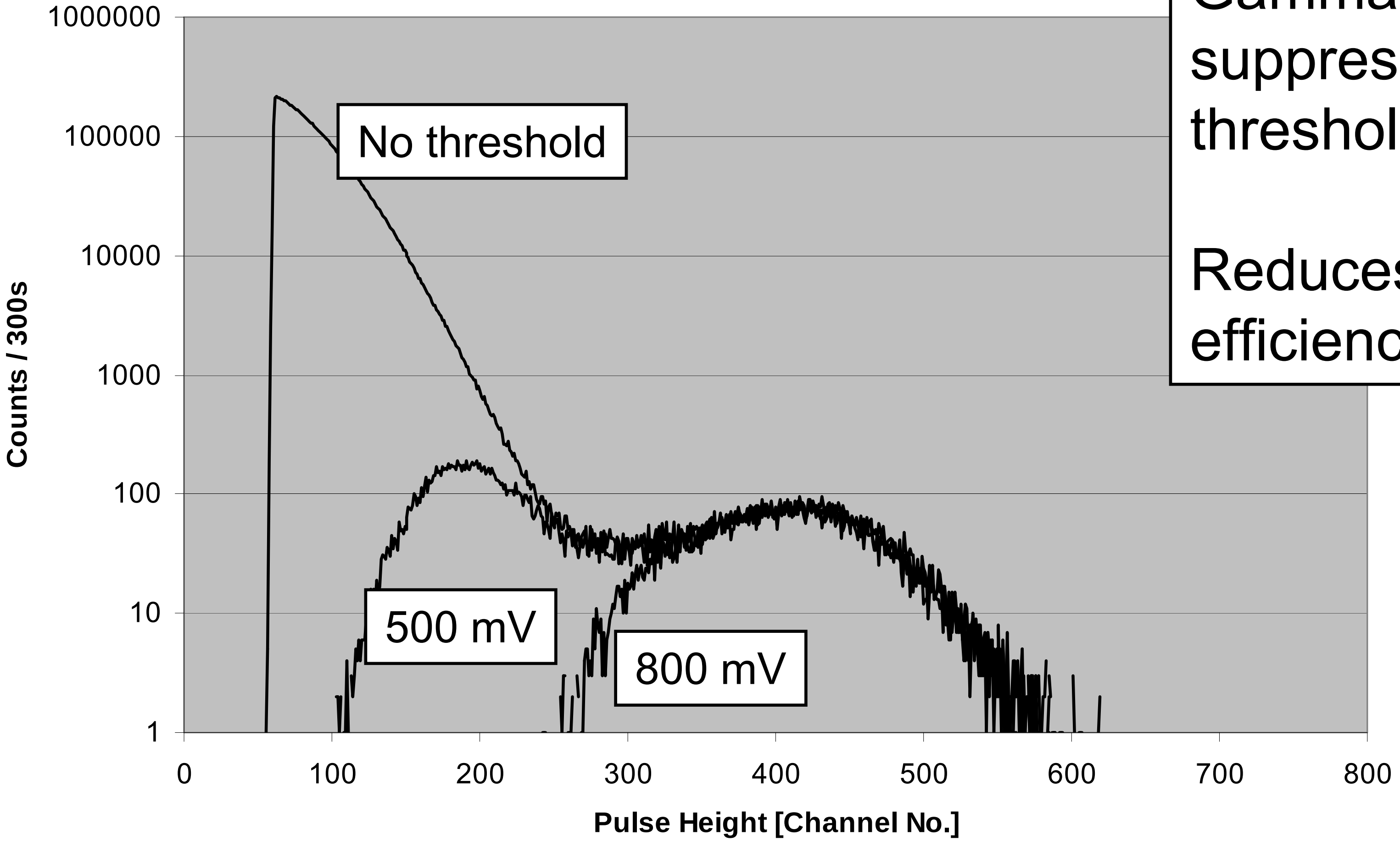
Effect of amplifier threshold



Gammas could be suppressed by threshold value

Reduces absolut efficiency for n

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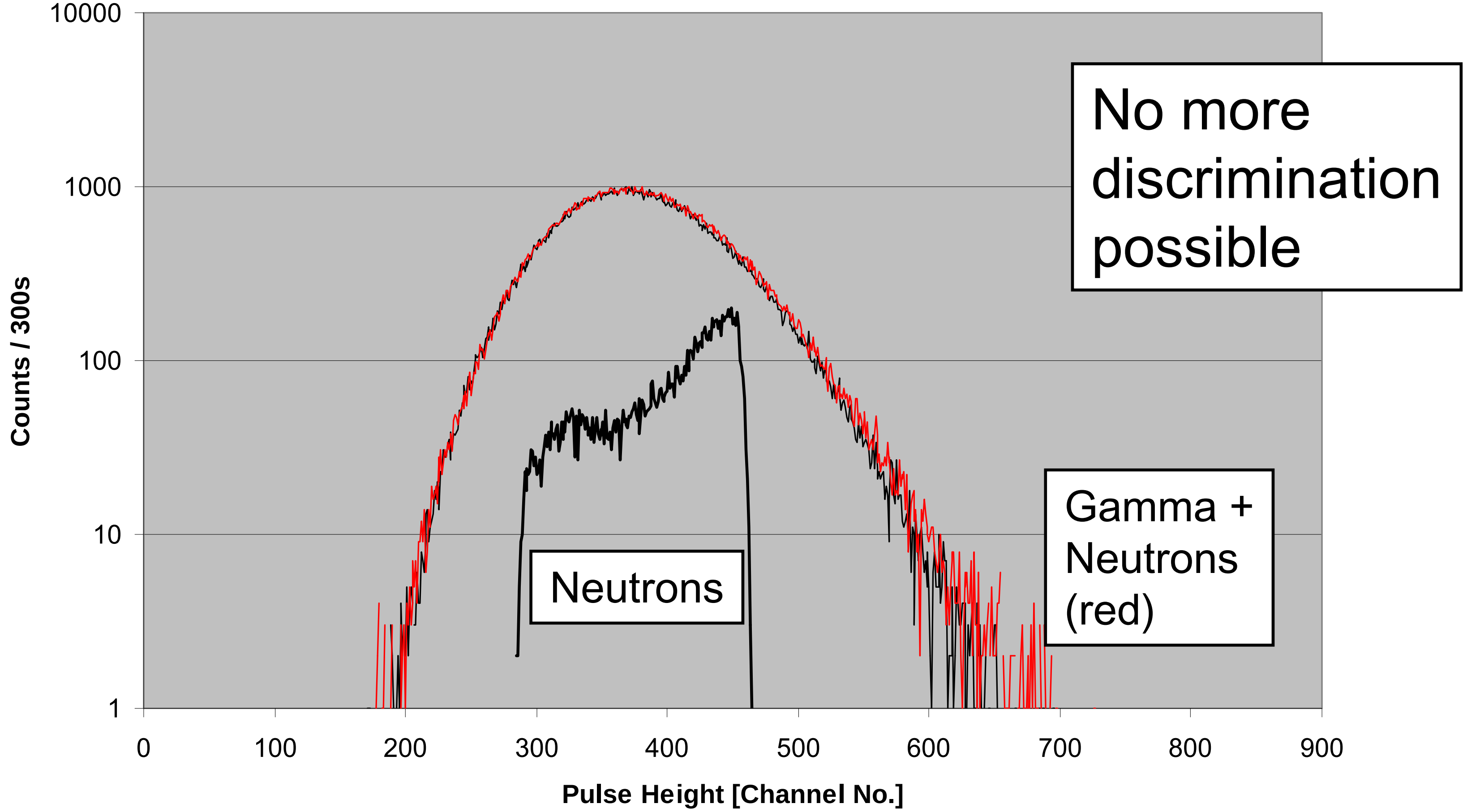
High Gamma dose rate

At 5.77 Gy/h (former slides 0.7 Gy/h) Gammas clearly dominate



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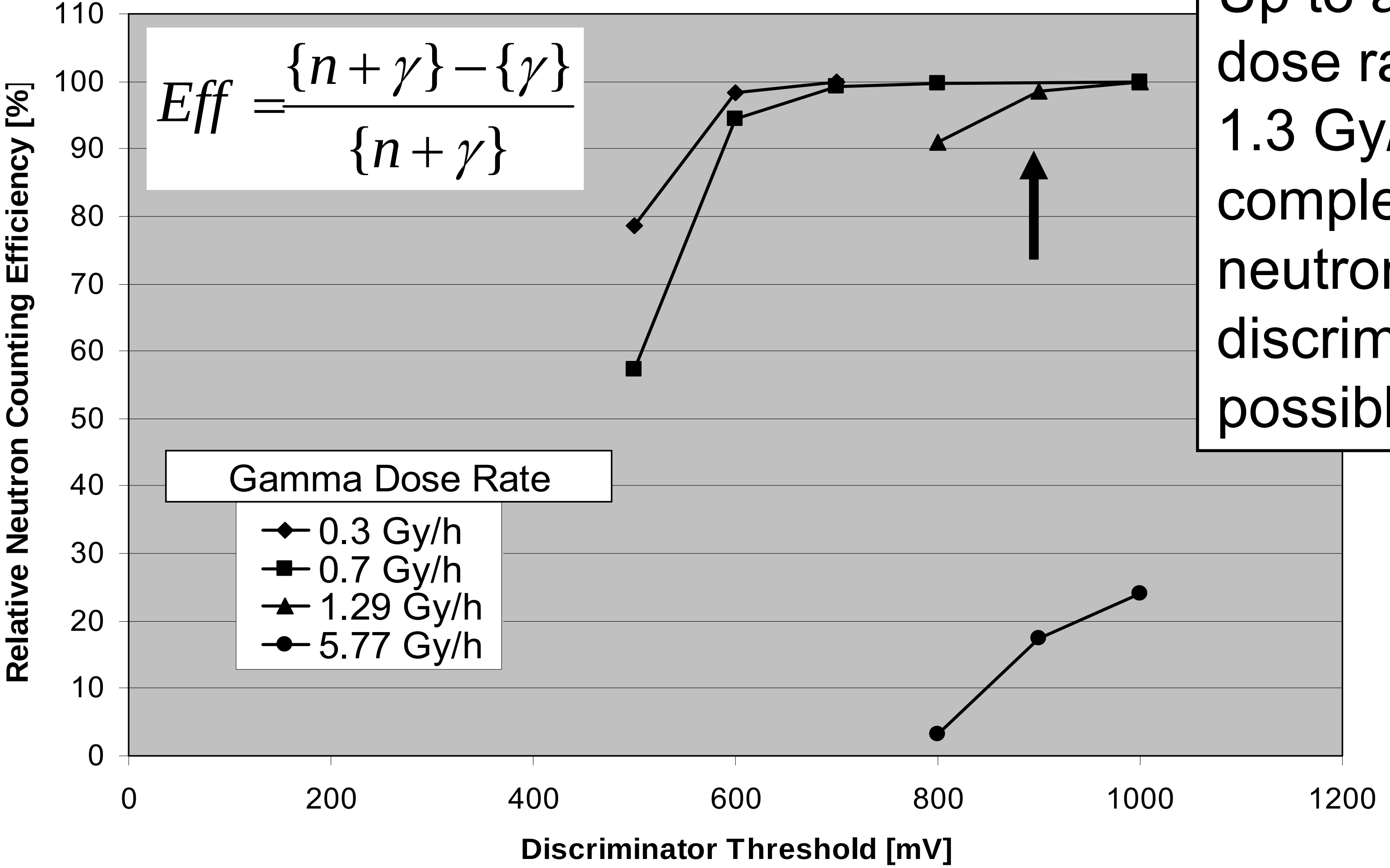
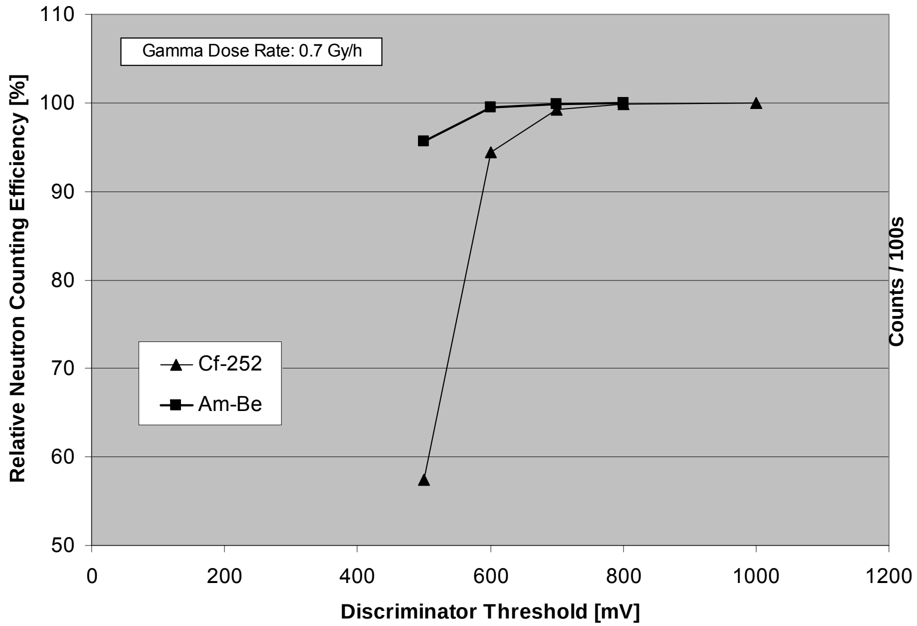
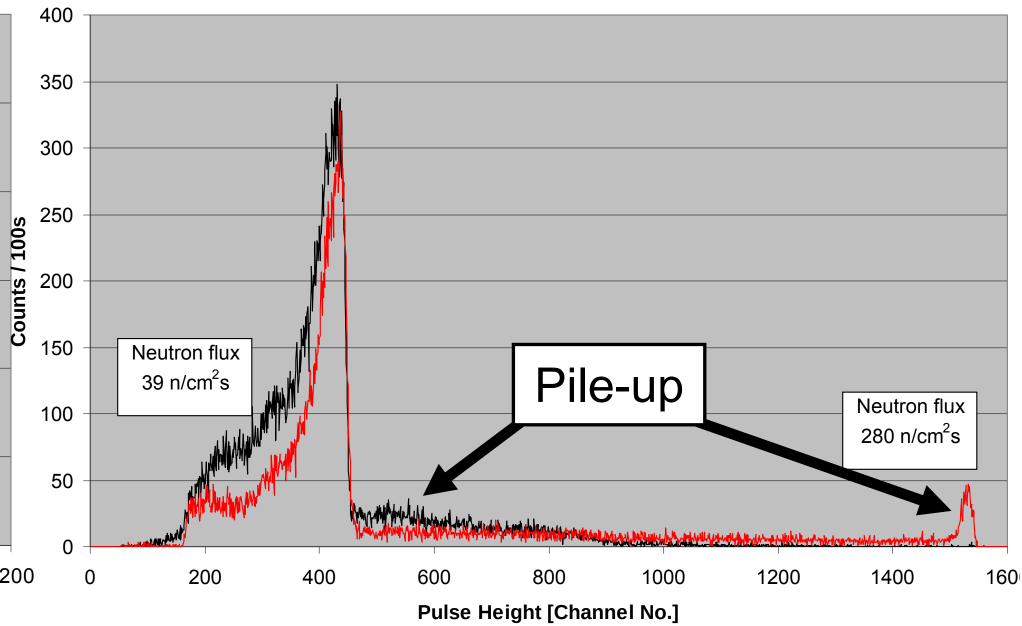
Efficiency vs. Threshold



Up to a Gamma dose rate of 1.3 Gy/h complete neutron/gamma discrimination possible

Influence of neutron flux and neutron energy





Am/Be source with 106.6 GBq
Flux: 29.7 n/cm^2 s
40 times the flux of Cf-252

Above threshold of ~ 700 mV
no change in discrimination

14 MeV DT neutrons, no additional Gamma
Flux: 39 and 280 n/cm^2•s

Large pile-up effects

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Summary of performed experiments

- Gamma and Neutron irradiation of IAEA employed He-3 counters and electronic
- Determination of relative and absolute efficiency as function of threshold setting
- No Gamma interference up to a dose rate of 1.3 Gy/h (Co-60)
- Pile-up at high neutron flux (neutron generator)
- Importance of testing detector together with accessory electronic module
- Threshold adjustment on electronic module from Petersburg Nuclear Physics Institute (PNPI) performed very well
- PDT110A electronic module has only logical output, no test point for threshold readout and only limited threshold adjustment reproducibility

Concepts for ^{3}He replacement: advantages and drawbacks

IAEA uses equipment to verify content of fissionable material in various physical forms => large number of different instruments

He-3 Tubes are used for simple neutron **counting** and neutron **coincidence** resp. **multiplicity** measurements. A replacement technology needs to be investigated with respect to:

- Absolute efficiency
- Gamma rejection
- Timing behavior in case of coincident techniques
- Other constrains, like size, shape, shock resistance, power supply requirements (including HV), vibration resistance, temperature effects…

Possibly not one single technology will fit for all applications

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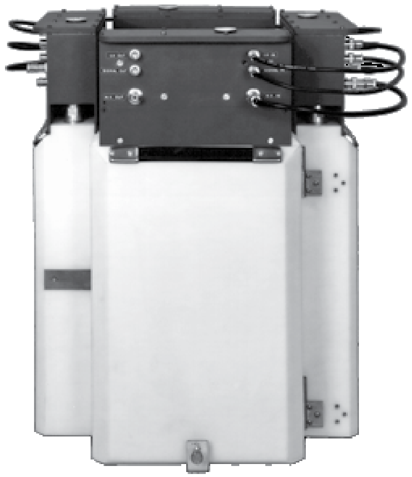
Some of IAEA Safeguards Equipment with He-3

Name	Code	# He-3 Tubes
Active Well Coincidence Counter	AWCC	42
Bird Cage Counter	BCNC	20
Canister Counter	PCAS	16
High Level Neutron Coincidence Counter	HLNC	18
Plutonium Canister Verification System	PCVS	12
Plutonium Scrap Multiplicity Counter	PSMC	80
Underwater Coincidence Counter	UWCC	8
Universal Fast Breeder Reactor Subassembly Counter	UFBC	12
Uranium Neutron Coincidence Collar	UNCL	18
Waste Crate Assay System	WCAS	98
Waste Drum Assay System	WDAS	64



UNCL

AWCC

WDAS

Large number of ^{3}He detector tubes in use

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Possible nuclear reactions for neutron detection

- Elastic scattering on Hydrogen (proton recoil)
- Radiative Capture
  - Cadmium-113
  - Gadolinium-157
- Capture with alpha emission
  - Lithium: $^{6}Li + n \rightarrow \alpha + T + 4.78$ MeV
  - Boron: $^{10}B + n \rightarrow \alpha + {}^{7}Li + 2.79$ MeV

Lithium and Boron are quite easily to enrich. Large quantities of enriched Lithium-6 might be a safeguard issue.

Enrichment of Cadmium and Gadolinium might not be as easy.

Possible Detector Techniques for replacement of ^{3}He tubes

- Lithium doped glass fibers
- LiZnS coated scintillator
- Lithium Glass alone or sandwiched with plastic scintillator
- Boron lined detectors and straw detectors
- Boron doped liquid and solid scintillator
- BF_3 proportional counter
- Cadmium-lined plastic scintillator
- Liquid scintillator with PSD
- Gadolinium lined plastic scintillators
- Bubble detectors (superheated drops)

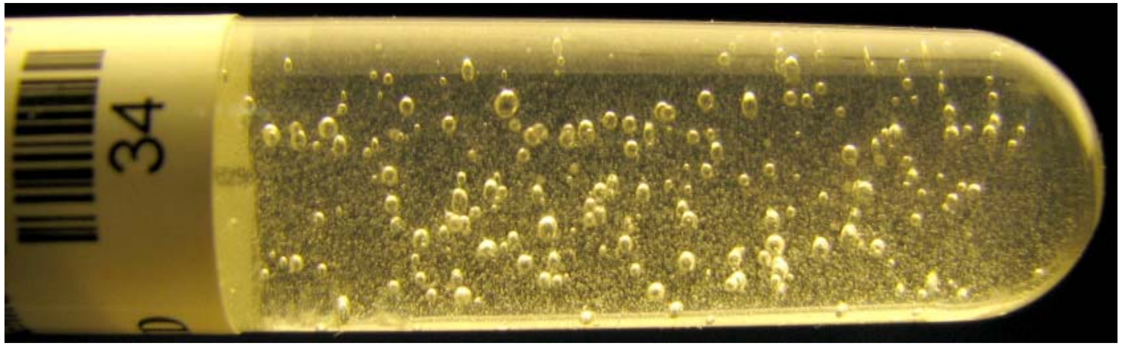
Boron Trifluorid (BF_3) proportional counter

- Presumably the easiest way to replace ^3He tubes
- B-10 has only slightly lower cross-section
- Good gamma discriminating properties
- BF_3 easily available in large quantities

But

- BF_3 is highly toxic
- High efficiency calls for enriched boron, increases price
- For good resolution admixtures are needed (like Ar)
  Reduces the boron density and thus overall efficiency
- Increased High Voltage needed (~ 2300 V)

Bubble detector



- Superheated liquid drops in viscous media
- Actual technology is offline method, computerized visual inspection
- Small number of bubbles → problems with statistics
- Pro: Tissue equivalent
- Large Volume possibly no problem
- Integrating instrument

Scintillators – Plastic and Liquids

Quality (FoM) Neutron – Gamma separation depends strongly on pulse height (neutron energy) and intensity (count rate)

Significant high Gamma back-ground will influence Gamma discrimination and thus neutron efficiency

Neutron spectrum from a large sample is different from a pure fission spectrum

Difficulties and problems not mentioned so far (esp. in high radiation environment) :

- Aging of scintillator
- Tight sealing of liquid scintillator (multiple temperature cycles)
- Aging of light guides (reduction of transmission)
- PMT: sensitivity to strong electromagnetic fields (esp. in NPPs)
- Aging of photocathode

Where can Fraunhofer-INT support?

- Qualification of detector components and detection systems in mixed gamma and neutron fields
  - Large number of possible neutron and gamma sources
  - Very high dose and dose rate possible
- Optimization of detection systems by Monte Carlo simulations (MCNP)
- Consulting on the choice of technology and implementation

Summary

- Irradiation facilities and experience at Fraunhofer INT
- Qualification of various ^{3}He detectors for IAEA
  - Gamma contribution could be suppressed completely up to a dose rate of about 1.3 Gy/h
- We are able to test prototype detectors under realistic conditions

Thank you for your attention

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