Active Interrogation of SNMs by use of IEC Fusion Neutron Generator

Kai Masuda[1], T. Masawa[2], Y. Yakahashi[2], T. Yagi[2], R. Nakamatsu[1], S. Fushimoto[3]

1 Inst. Advanced Energy, Kyoto Univ.
2 Research Reactor Inst., Kyoto Univ.
3 Pony Industry Co. Ltd.

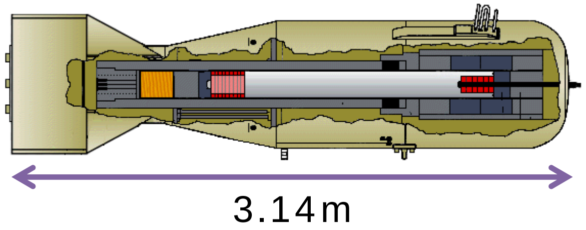
R&D Program for Implementation of Anti-Crime and Anti-Terrorism Technologies for a Safe and Secure Society promoted by Japan Science and Technology Agency

Talk Outine

- Introduction
  - Background
  - Project overview
- Neutron-Based Rapid Screening System
  - System layout – container trucks, IECs, detectors,
  - Pulsed IEC and HV power supply
- Detection Methods & Exp. Results
  - Delayed Neutron Noise Analysis (DNNA)
  - Threshold Energy Neutron Analysis (TENA)
- Concluding Summary & Plans

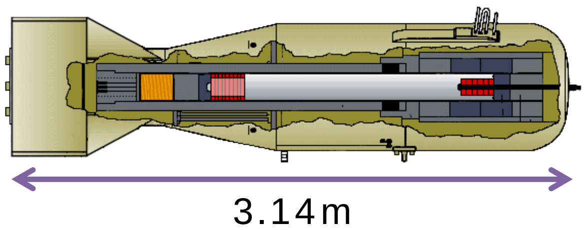
Nuclear Terrorism Threats

- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



Nuclear Terrorism Threats

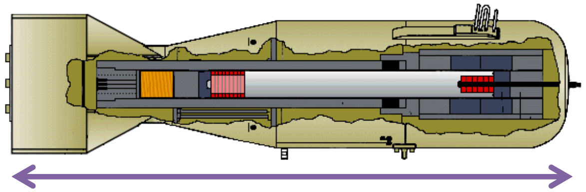
- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu

Nuclear Terrorism Threats

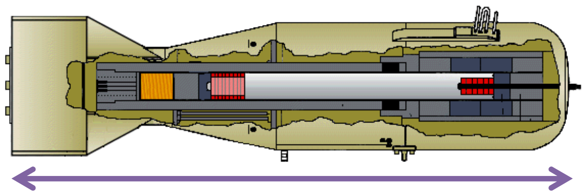
- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu
- ^{235}U Hiroshima-type is more troublesome.

Nuclear Terrorism Threats

- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



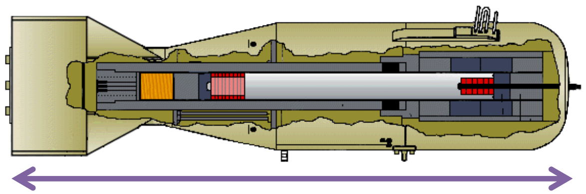
- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu
- ^{235}U Hiroshima-type is more troublesome.
  - passive detection is impossible unlike ^{239}Pu

Passive Gamma-ray detectors
Effective to ^{239}Pu

Pony Industry Co. Ltd.

Nuclear Terrorism Threats

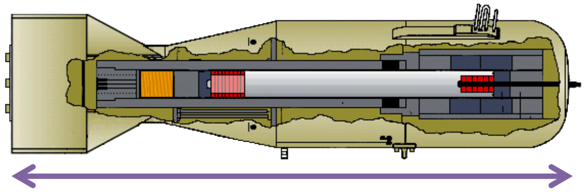
- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu
- ^{235}U Hiroshima-type is more troublesome.
  - passive detection is impossible unlike ^{239}Pu
  - easy to make w/o test bans
  - assembling in the target nation is possible

Nuclear Terrorism Threats

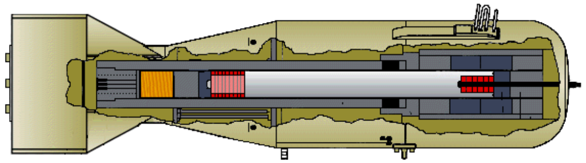
- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu
- ^{235}U Hiroshima-type is more troublesome.
  - passive detection is impossible unlike ^{239}Pu
  - easy to make w/o test bans
  - assembling in the target nation is possible
  - identification by shape is not effective enough

Nuclear Terrorism Threats

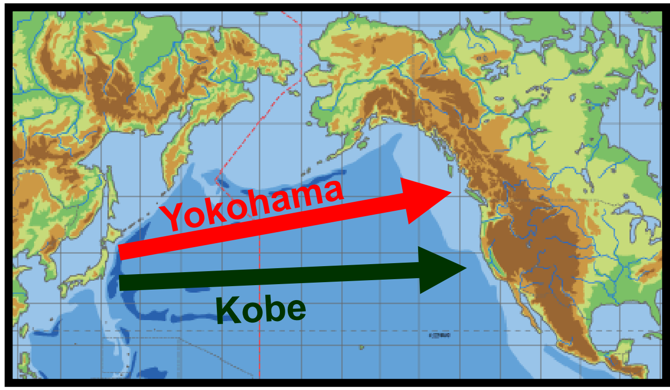
- Conventional gun-type nuclear weapon: 30 – 60 kg of ^{235}U



- Modern tactical nuclear weapon: 10 – 30 kg of ^{239}Pu
- ^{235}U Hiroshima-type is more troublesome.
  - passive detection is impossible unlike ^{239}Pu
  - easy to make w/o test bans
  - assembling in the target nation is possible
  - identification by shape is not effective enough
- Transportation of tens kg of ^{235}U – air cargo, land transportation, spy ship, sea container.

Megaports Initiative (2007)

- Mandatory SNM screening of all US-bound containers at their port of origin from 2012.

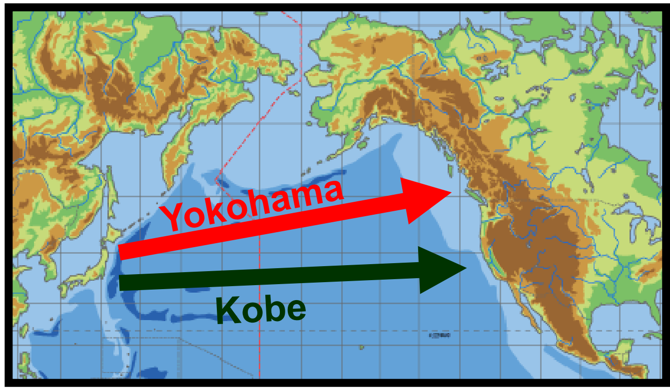


20ft container
8 ft x 8 ft x 20 ft

400 containers / day from Yokohama

Megaports Initiative (2007)

- Mandatory SNM screening of all US-bound containers at their port of origin from 2012.



20ft container
8 ft x 8 ft x 20 ft

400 containers / day from Yokohama

- It has been delayed 2x2 years (until 2016), due to lack of SNM detection system.

CONTAINER INDUSTRY

WorldCargo news

Container scanning deadline extended

After encountering considerable opposition, the planned introduction in 2012 of a new security regime requiring all US-bound containers to be screened at their foreign port of origin has been postponed. Its enforcement has been delayed two years until July 2014.

Although mandatory screening of all US-bound containers at their foreign port of origin has been delayed two years (until 2014), the issue of container port security remains high on the agenda

Other detractors pointed out that the

gramme to ensure trade moving to/from

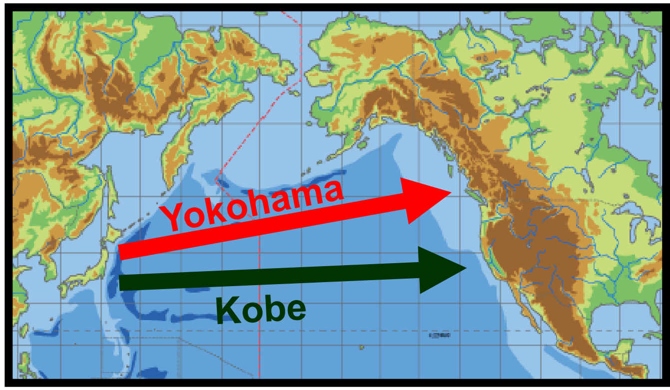
Working in conjunction with the

by a feasibility study carried out by the CBP itself, together with the US Department of Energy (DoE), which conclusively highlighted the problems inherent in achieving a 100% scan rate at any containerport.

SFI programme

Megaports Initiative (2007)

- Mandatory SNM screening of all US-bound containers at their port of origin from 2012.



20ft container
8 ft x 8 ft x 20 ft

400 containers / day from Yokohama

- It has been delayed 2x2 years (until 2016), due to lack of SNM detection system.

CONTAINER INDUSTRY

WorldCargo news

Container scanning deadline extended

After encountering considerable opposition, the planned introduction in 2012 of a new security regime requiring all US-bound containers to be screened at their foreign port of origin has been postponed. Its enforcement has been delayed two years until July 2014.

Although mandatory screening of all US-bound containers at their foreign port of origin has been delayed two years (until 2014), the issue of container port security remains high on the agenda

by a feasibility study carried out by the CBP itself, together with the US Department of Energy (DoE), which conclusively highlighted the problems inherent in achieving a 100% scan rate at any containerport.

SFI programme

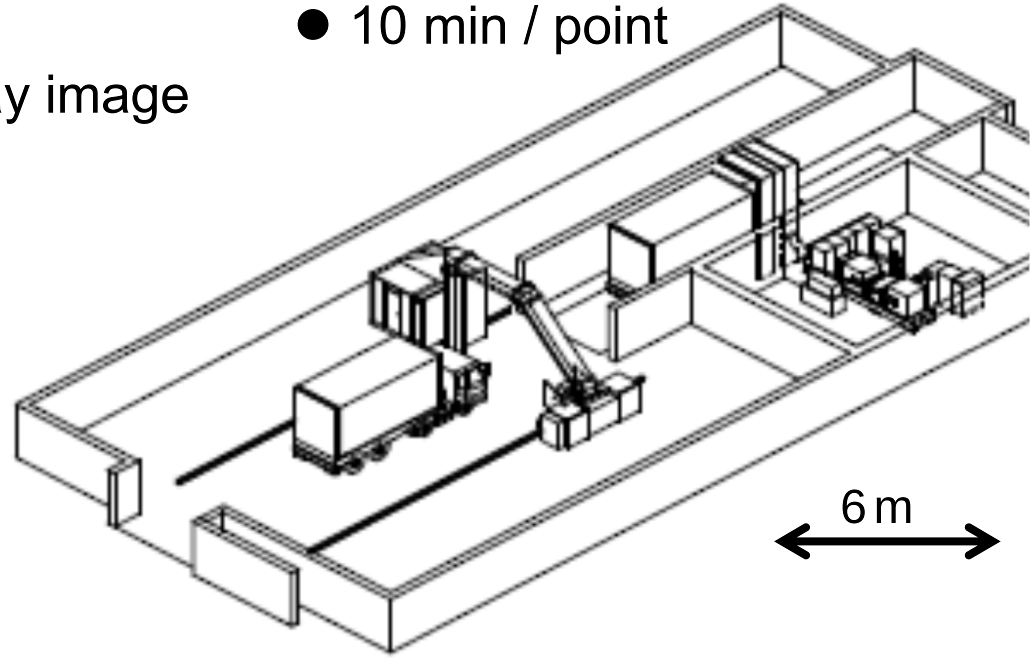
Very rapid (2 min/container) inspection system is required.

- JPN gov. will setup 2-3 central seaports.
- Our proposal is to built SNM screening facilities in those central seaports.

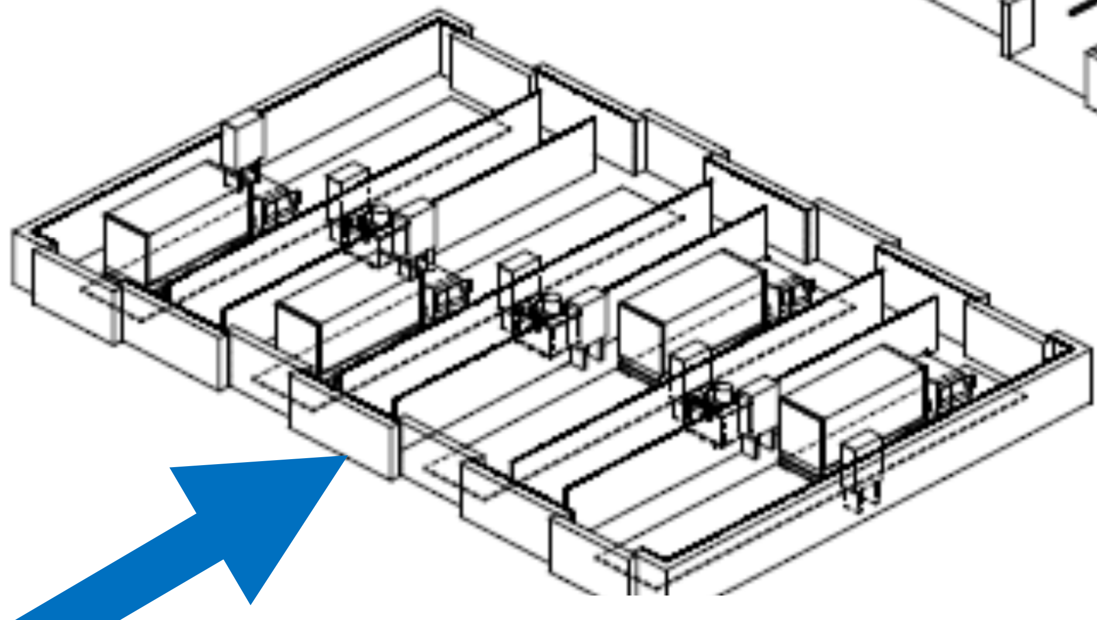
Project Overview

3. LCS γ-ray beam
for isotope identification
- 10 min / point

2. X-ray image



1. Neutron-based system



400 containers / day

Project Overview

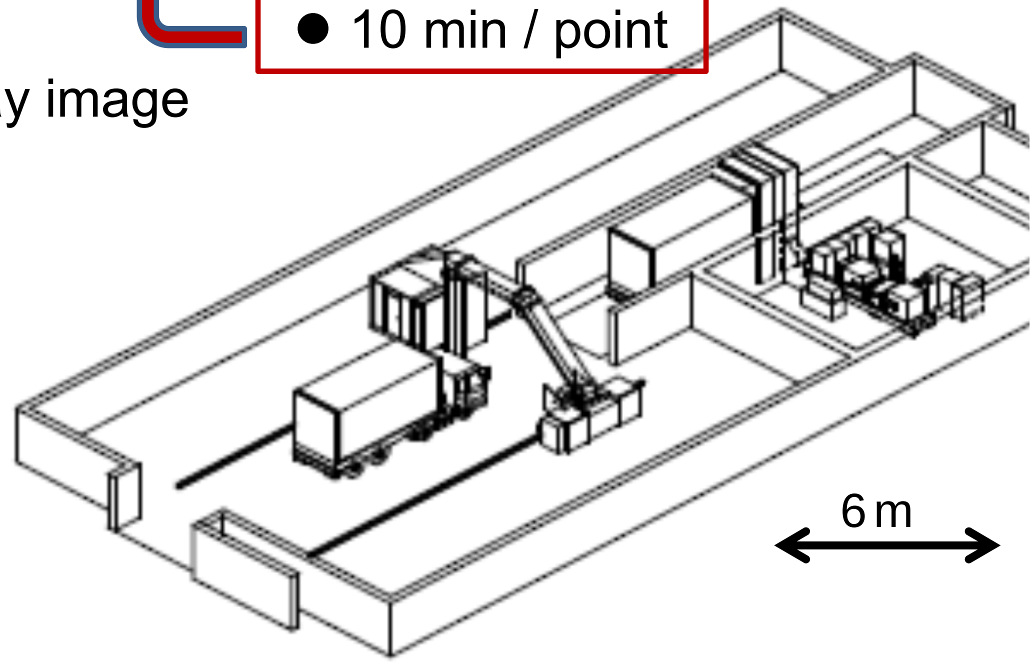
Scanning whole volume impossible.

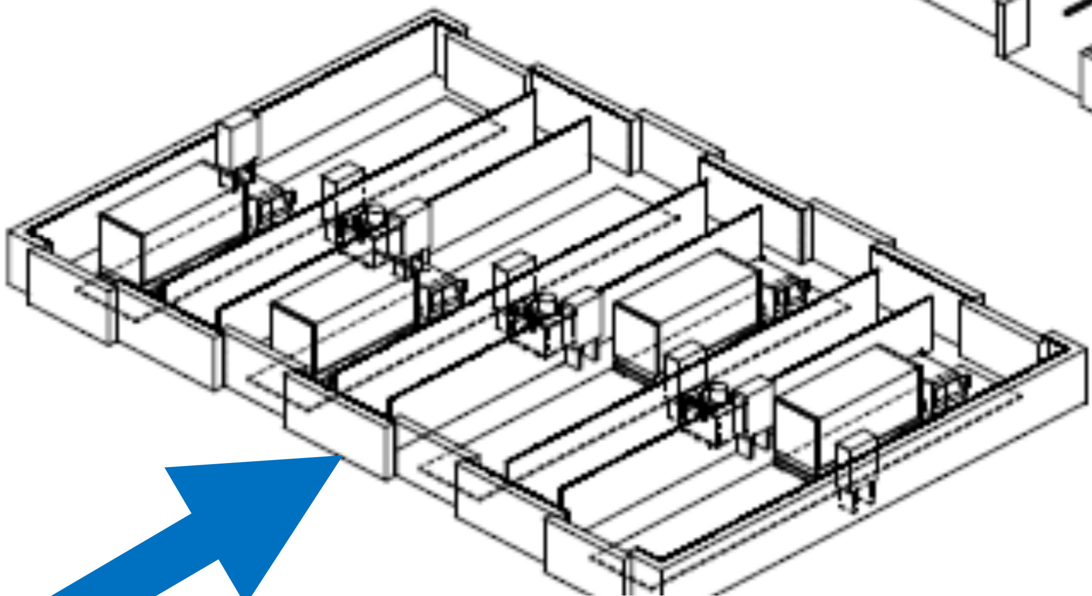
3. LCS γ-ray beam
for isotope identification

- 10 min / point

2. X-ray image

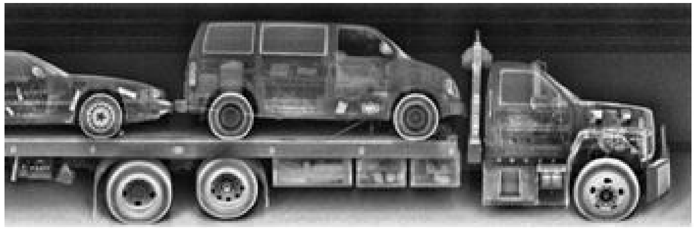
1. Neutron-based system





400 containers / day

Project Overview

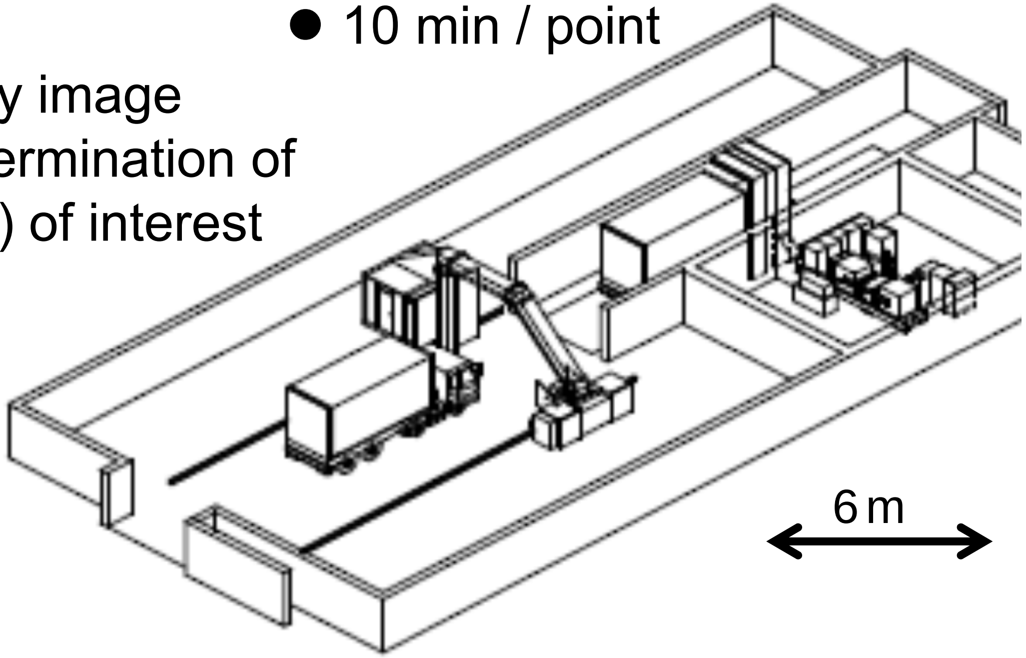


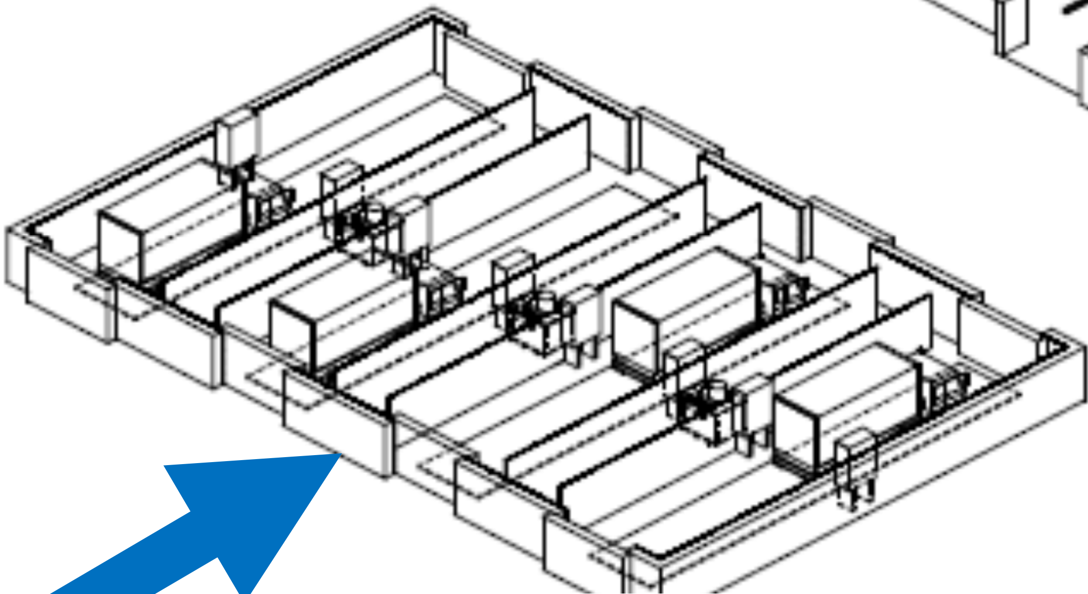
Pony Industry Co. Ltd.

1. Neutron-based system

2. X-ray image for determination of point(s) of interest

3. LCS γ-ray beam for isotope identification
- 10 min / point





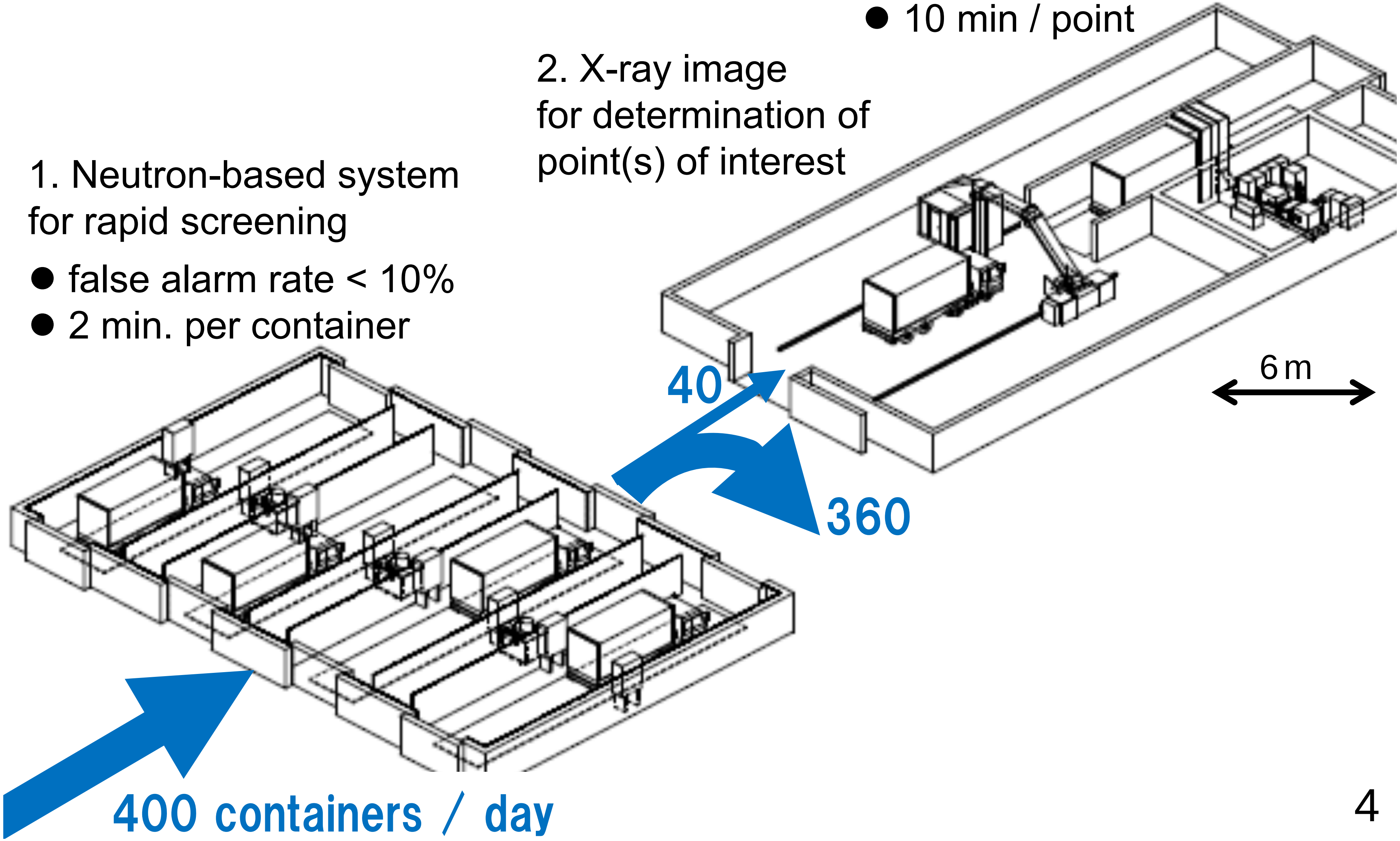
400 containers / day

Project Overview

1. Neutron-based system for rapid screening
   - false alarm rate < 10%
   - 2 min. per container

2. X-ray image for determination of point(s) of interest

3. LCS γ-ray beam for isotope identification
   - 10 min / point



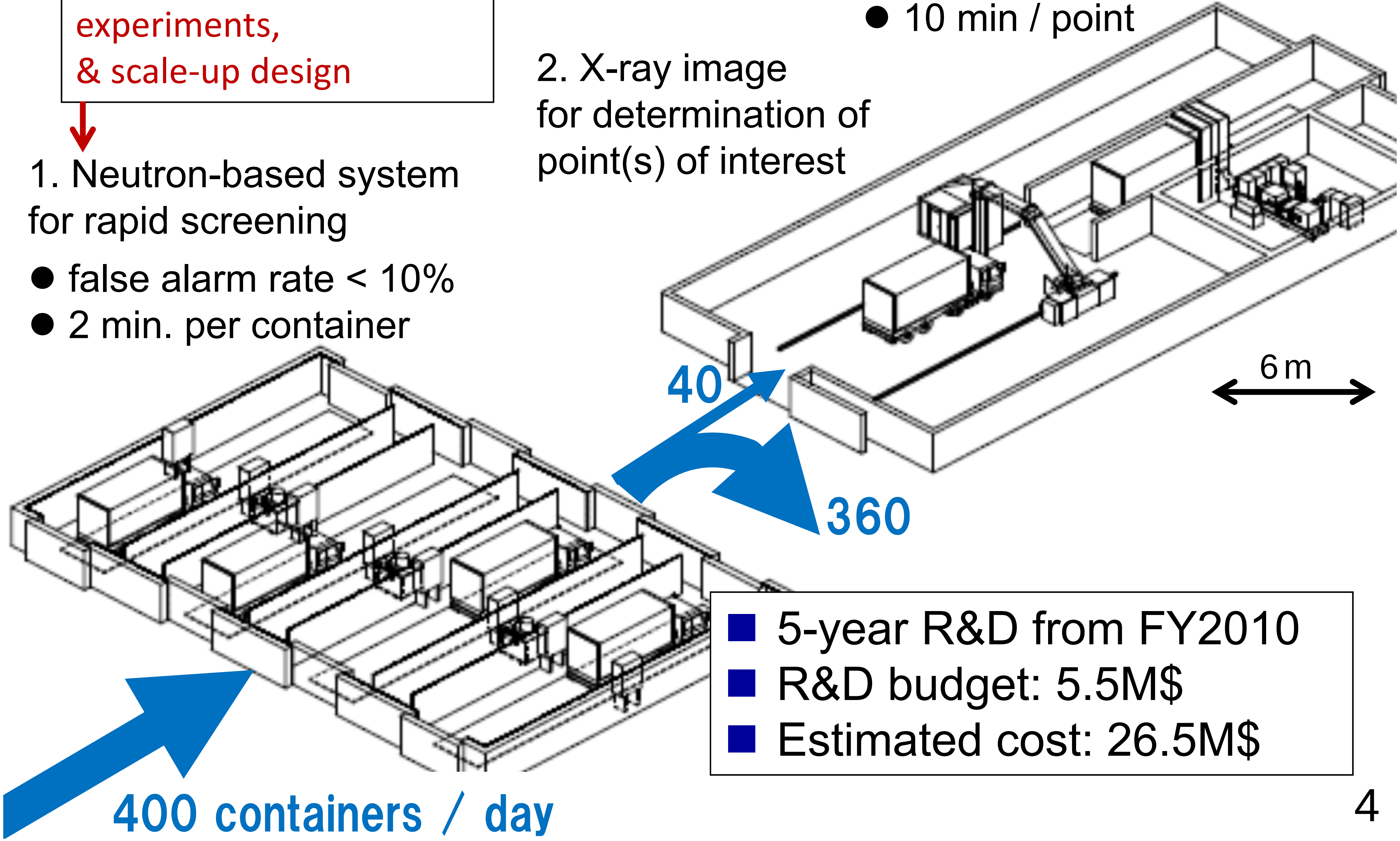
Project Overview

Proof-of-principle,
reduced-scale prototype experiments,
& scale-up design

1. Neutron-based system for rapid screening
- false alarm rate < 10%
- 2 min. per container

2. X-ray image for determination of point(s) of interest

3. LCS γ-ray beam for isotope identification
- 10 min / point



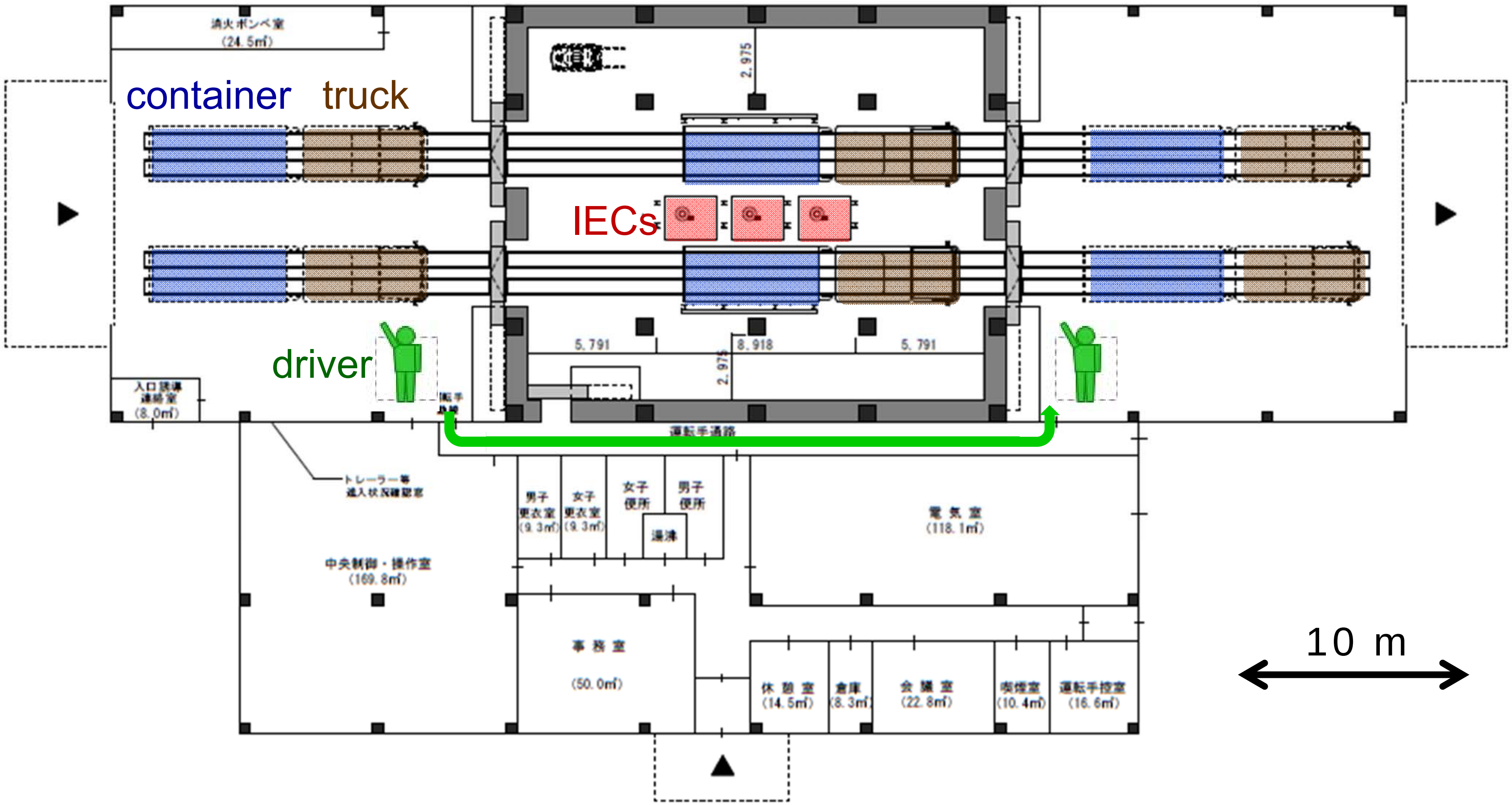
- 5-year R&D from FY2010
- R&D budget: 5.5M$
- Estimated cost: 26.5M$

Neutron-Based Screening Facility

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan

2 containers / 10 min

- 5 min for neutron-irradiation/detection, and
- 5 min for replacement of container trucks.

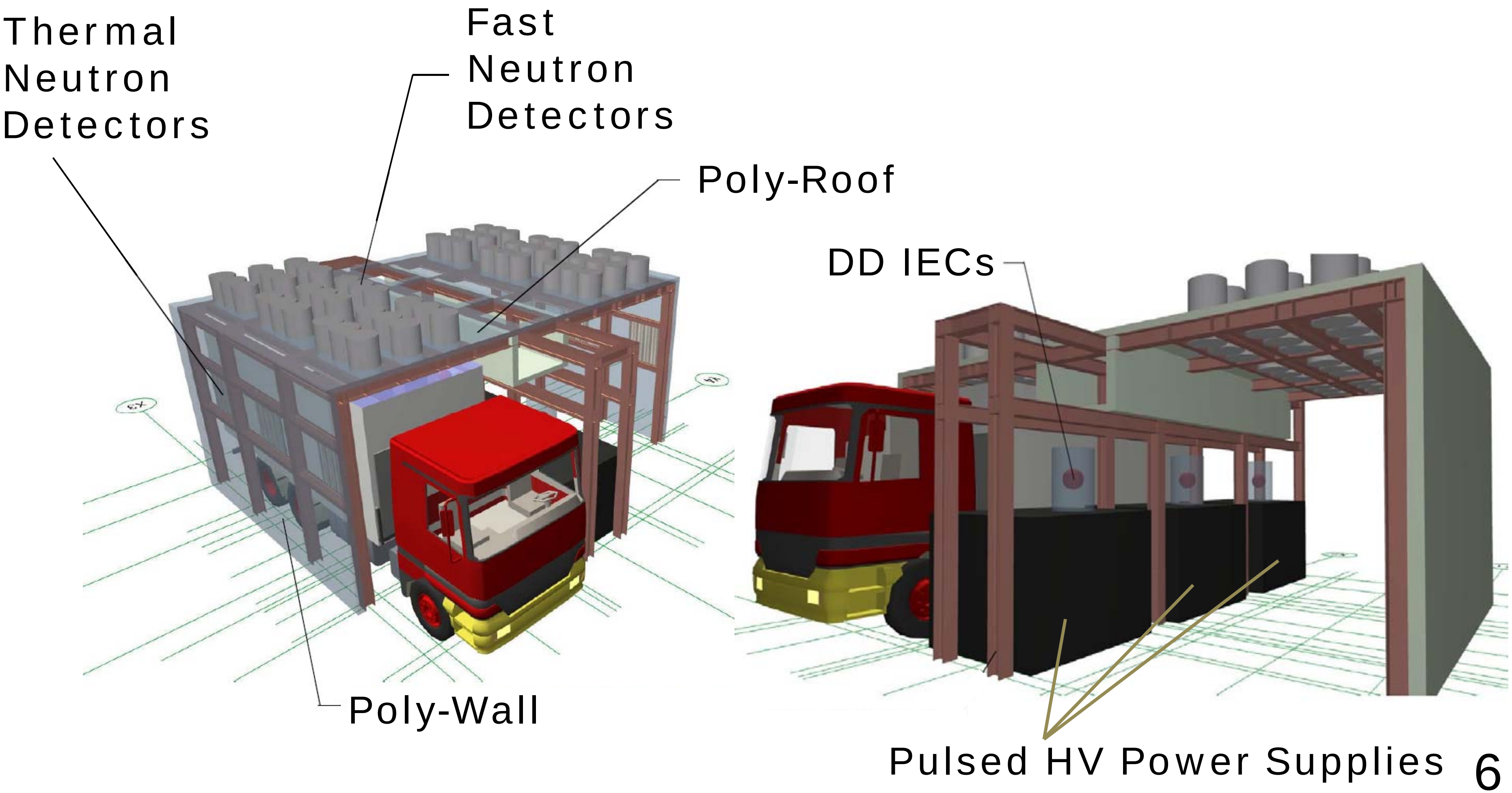


Neutron-Based Screening System

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan

Two container trucks are inspected simultaneously with

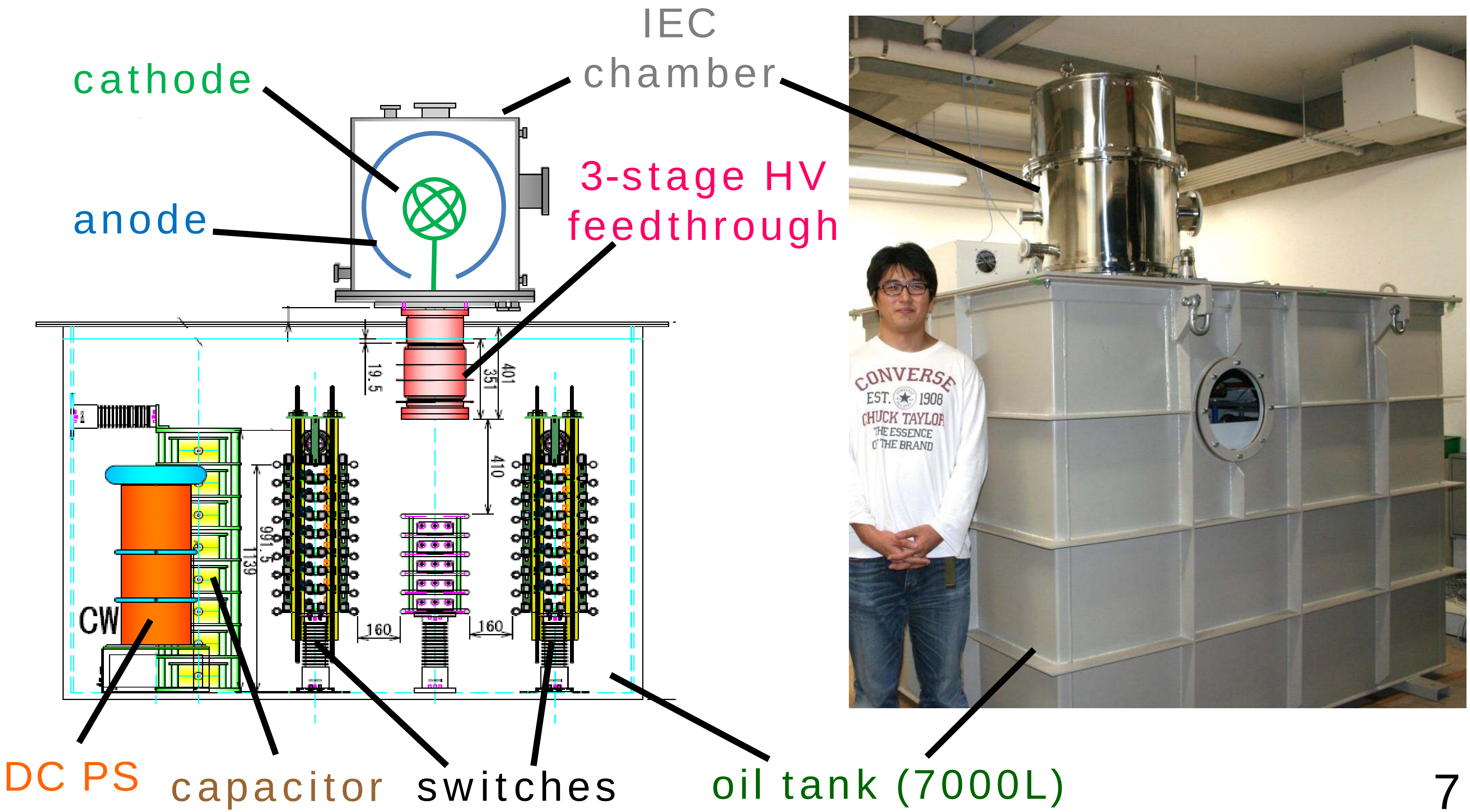
- Three pulsed DD-IECs (10^8 n/sec),
- 450 ^{3}He detectors (1" dia., 1m length) or more BF_3 detectors,
- 54 NE213 detectors (5" dia., 4" length) or fewer TMFDs.



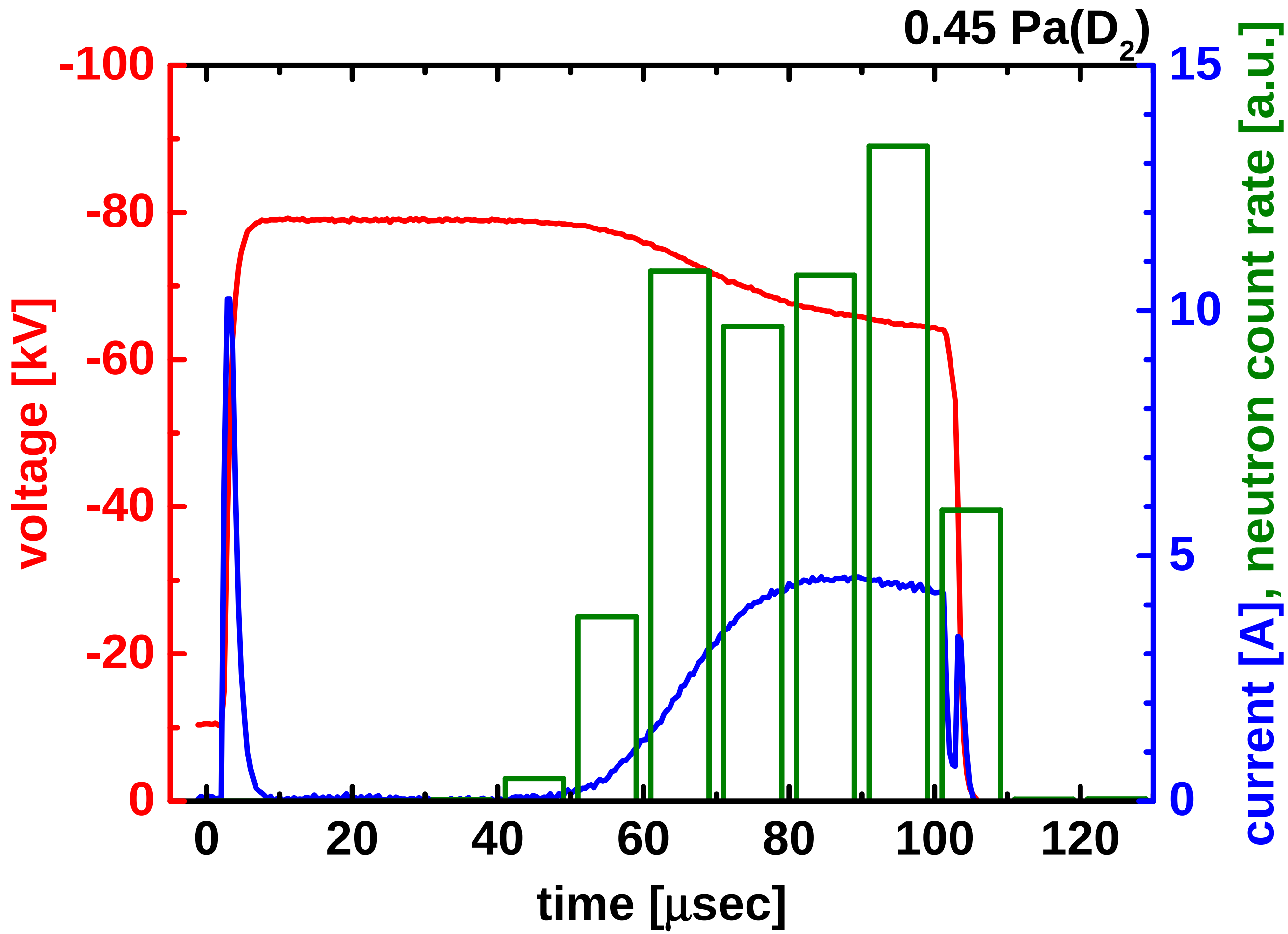
Newly Developed Pulsed IEC

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan

- All in one grounded tank ➡ Low EM noise emission
- Dual 200 kV switches ➡ Quick pulse fall-off



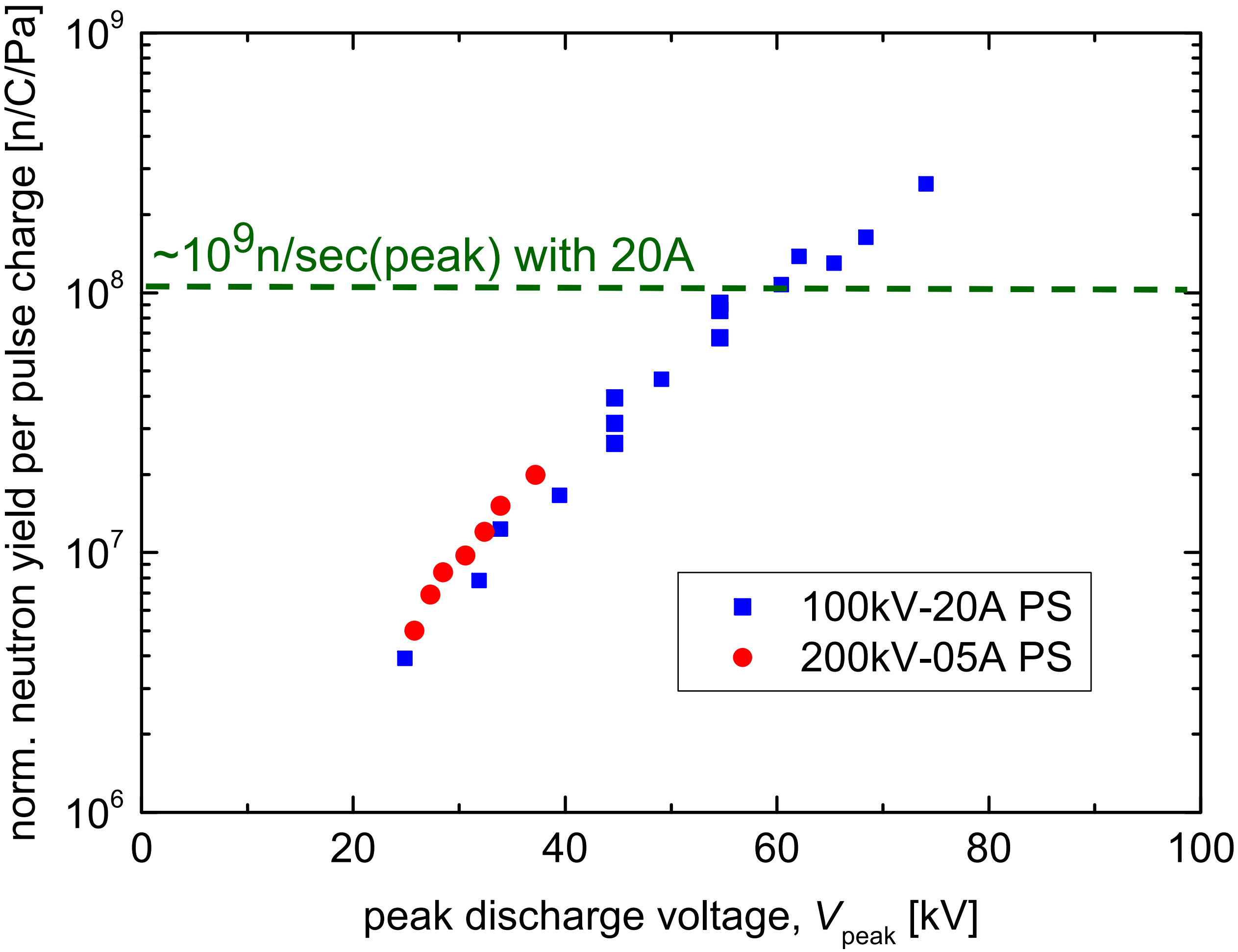
Typical Pulse Shapes of V, I and NPR



Details will be given tomorrow.

Experimental Pulsed Neutron Yield

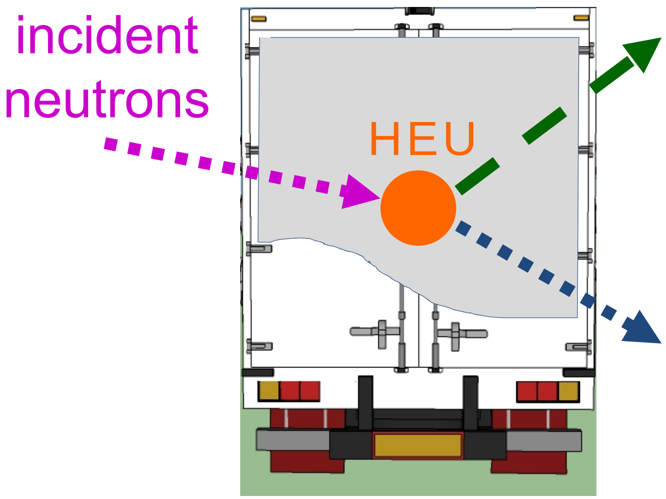
- Experimental tests were carried out with two pulsed HV PSs.
- 100kV-20A PS will be used for demo. because of transportation/ space limitations and oil/radiation regulations in KUCA facility where ^{235}U can be used.



Details will be given tomorrow.

Neutron-In Neutron-Out Detection of SNMs

A principal challenge is to distinguish the secondary neutrons from the probing neutrons.



delayed neutrons (<1%)

Easier approach,

but much less signals.

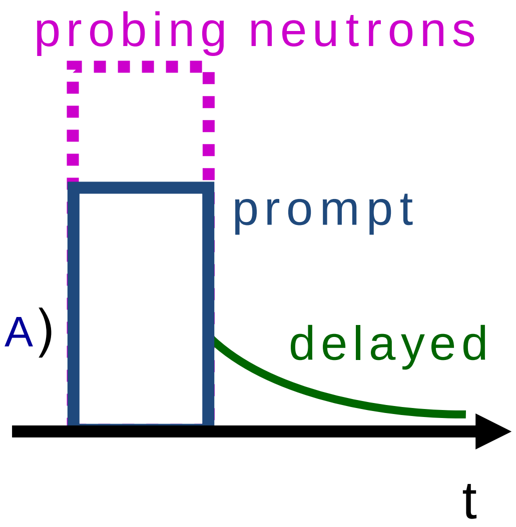
cf. Delayed Neutron Analysis (DNA)

prompt neutrons (>99%)

Much more plentiful,

but need to separate out from probing neutrons

cf. Differential Die-Away Analysis (DDAA)

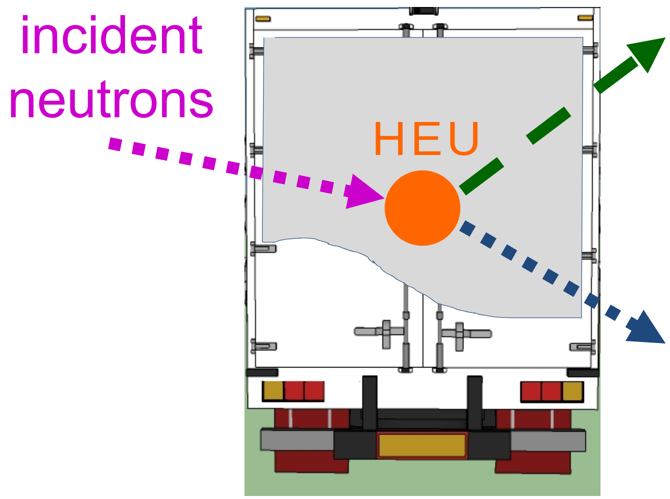


Either DNA or DDAA requires very intense NGs (DT mandatory).

Neutron-In Neutron-Out Detection of SNMs

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan

A principal challenge is to distinguish the secondary neutrons from the probing neutrons.



delayed neutrons (<1%)

Easier approach,

but much less signals.

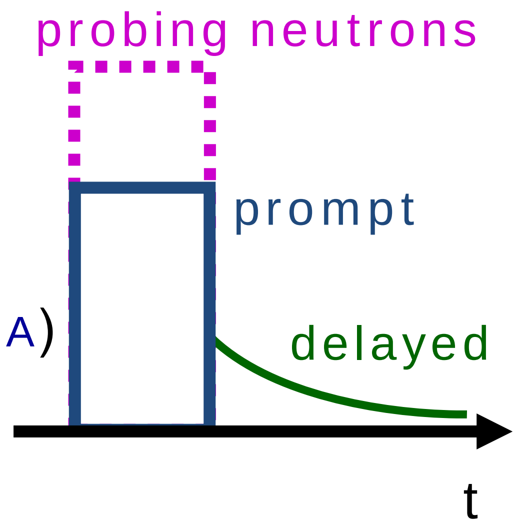
cf. Delayed Neutron Analysis (DNA)

prompt neutrons (>99%)

Much more plentiful,

but need to separate out from probing neutrons

cf. Differential Die-Away Analysis (DDAA)

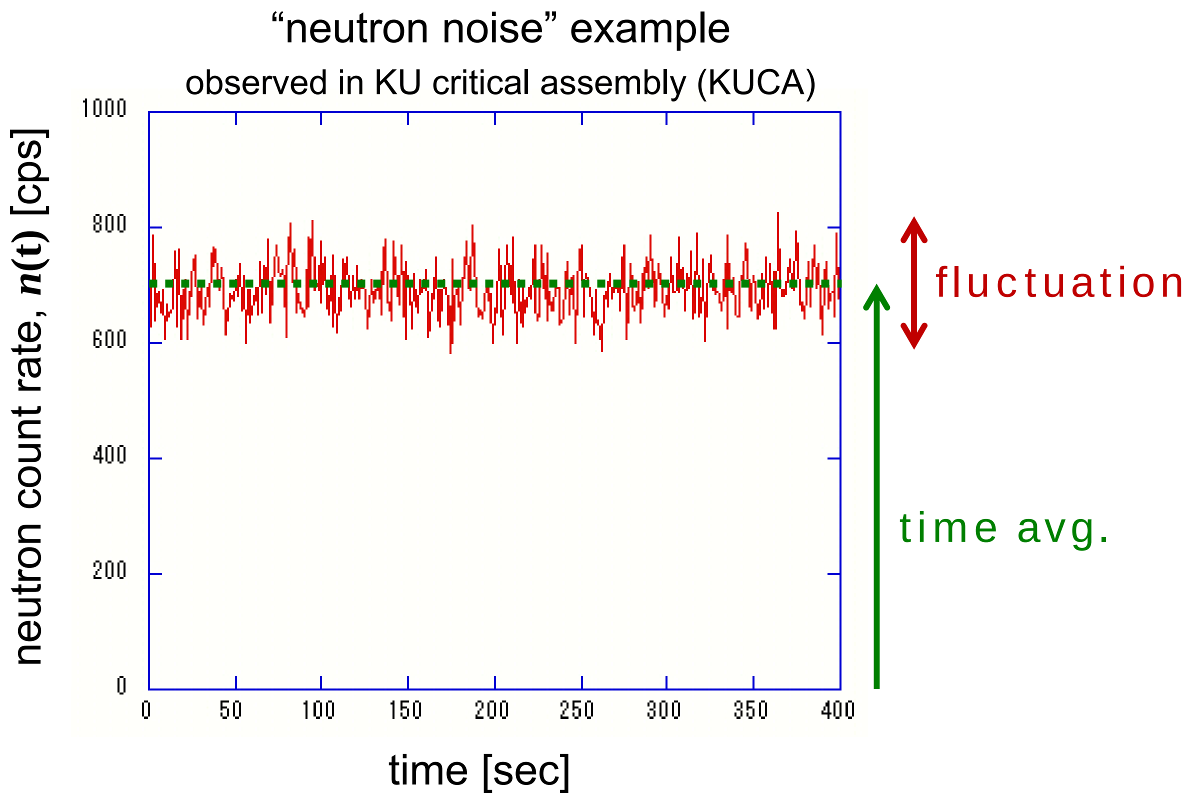


Either DNA or DDAA requires very intense NGs (DT mandatory).

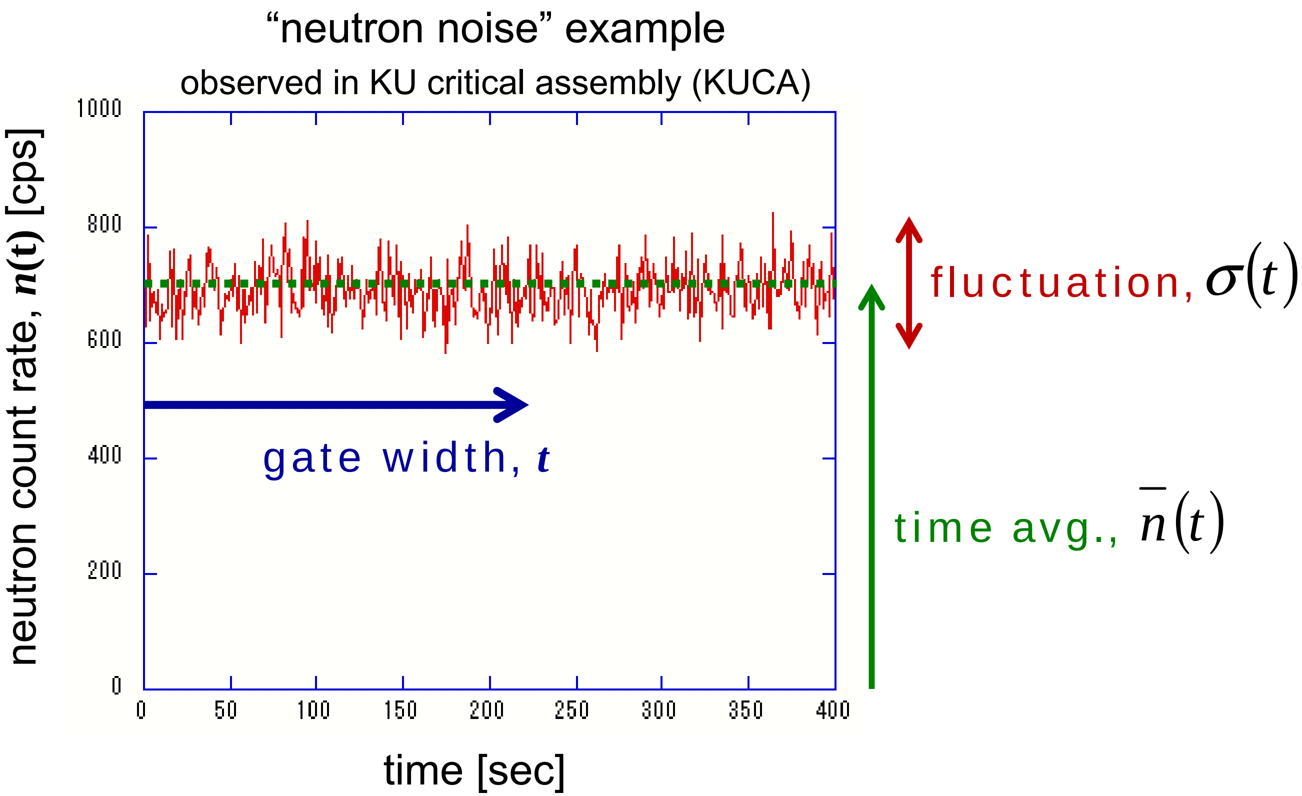
New techniques are being developed.

1. Delayed Neutron Noise Analysis (DNNA)
2. Threshold Energy Neutron Analysis (TENA)

What is “Neutron Noise” ?



"Neutron Noise" Contains Signature of Fission Chain Reactions



$$Y(t) = \frac{\sigma^2(t)}{\bar{n}(t)} - 1$$

$Y(\infty) = 0$ random neutrons (Poisson distribution)

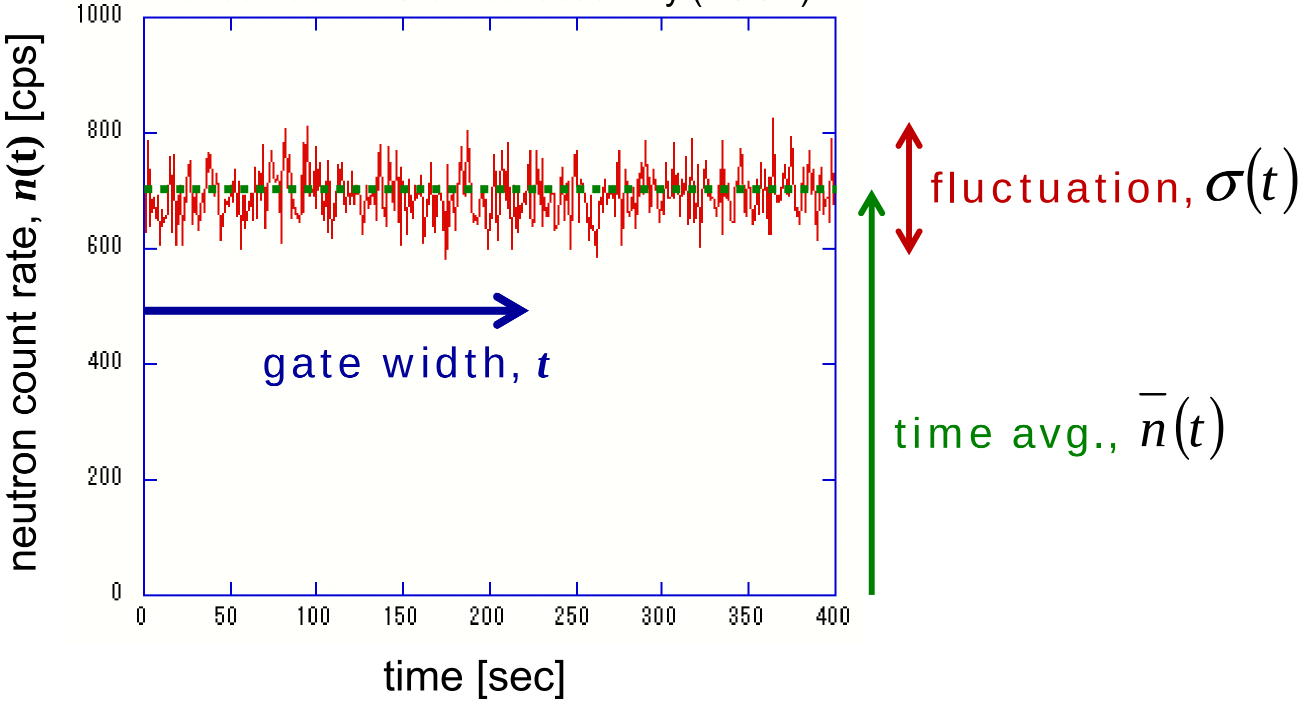
$Y(\infty) > 0$ correlated neutrons

Basic Neutron Noise Analysis (NNA)

- Well developed method in fission reactor physics field.
- Characterizes neutron multiplication factor due to fission chain reactions.

"neutron noise" example

observed in KU critical assembly (KUCA)

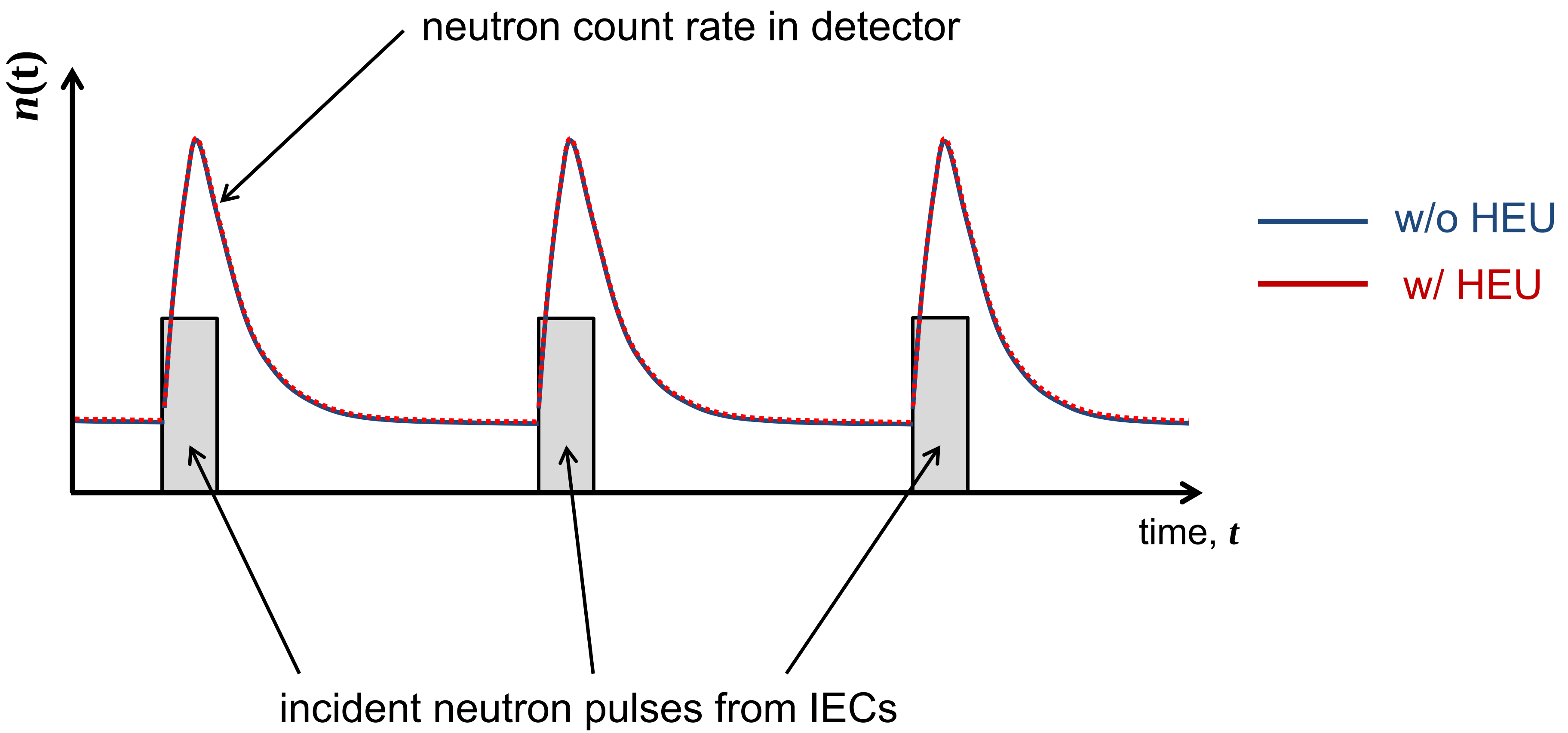


$$Y(t) = \frac{\sigma^2(t)}{\overline{n}(t)} - 1$$

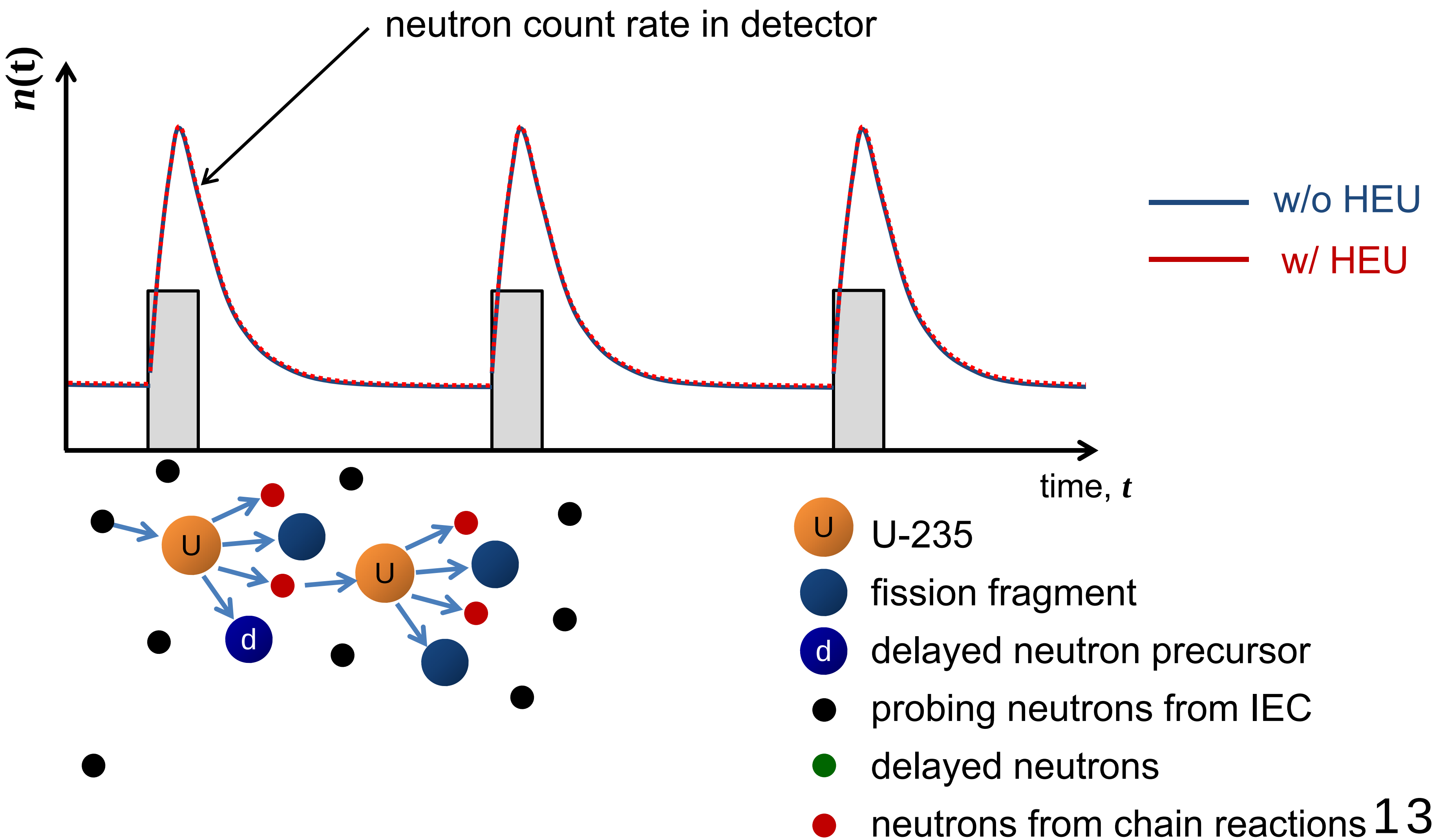
$Y(\infty) = 0$ random neutrons (Poisson distribution)

$Y(\infty) > 0$ correlated neutrons

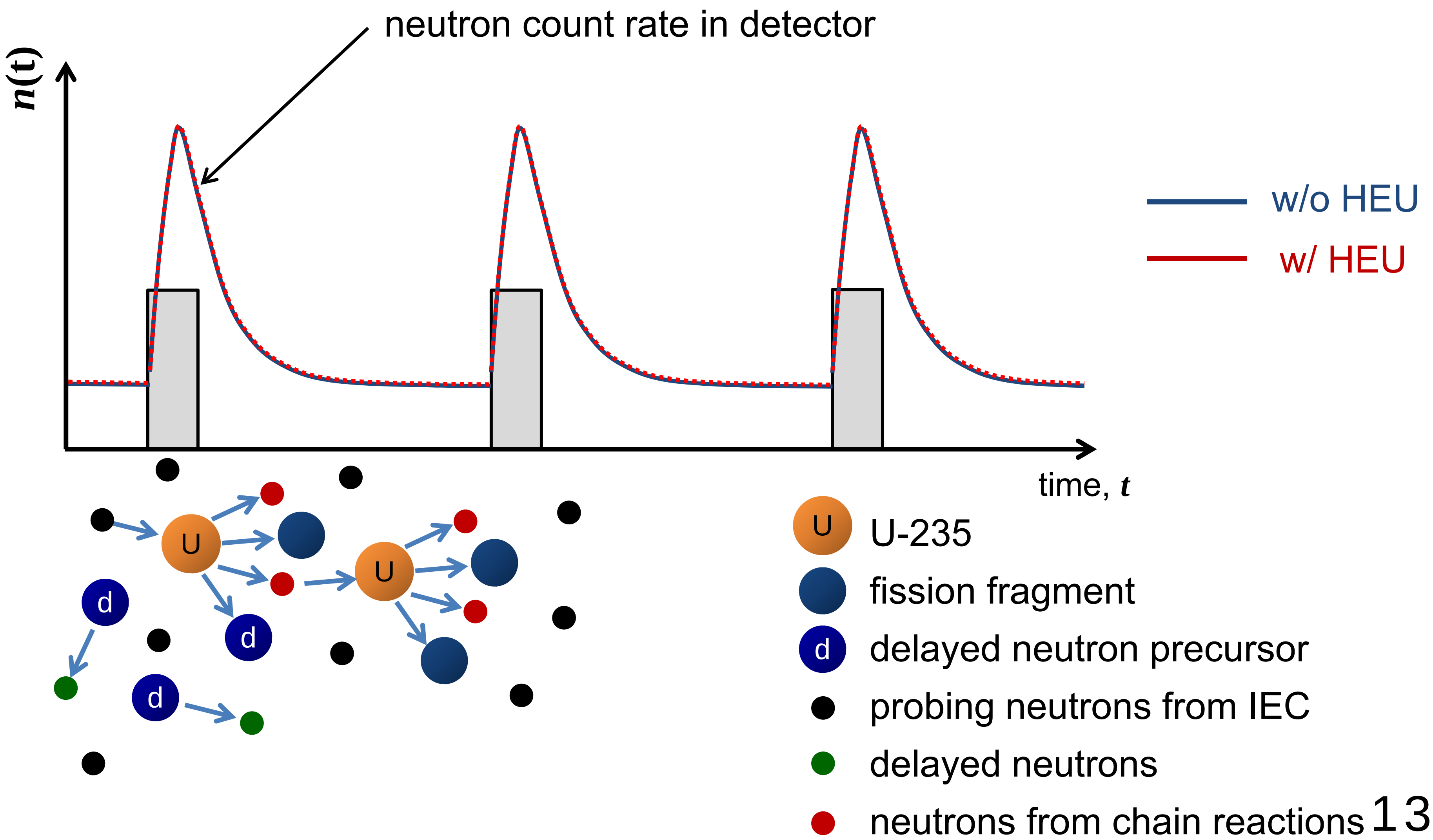
Delayed Neutron Noise Analysis (DNNA)



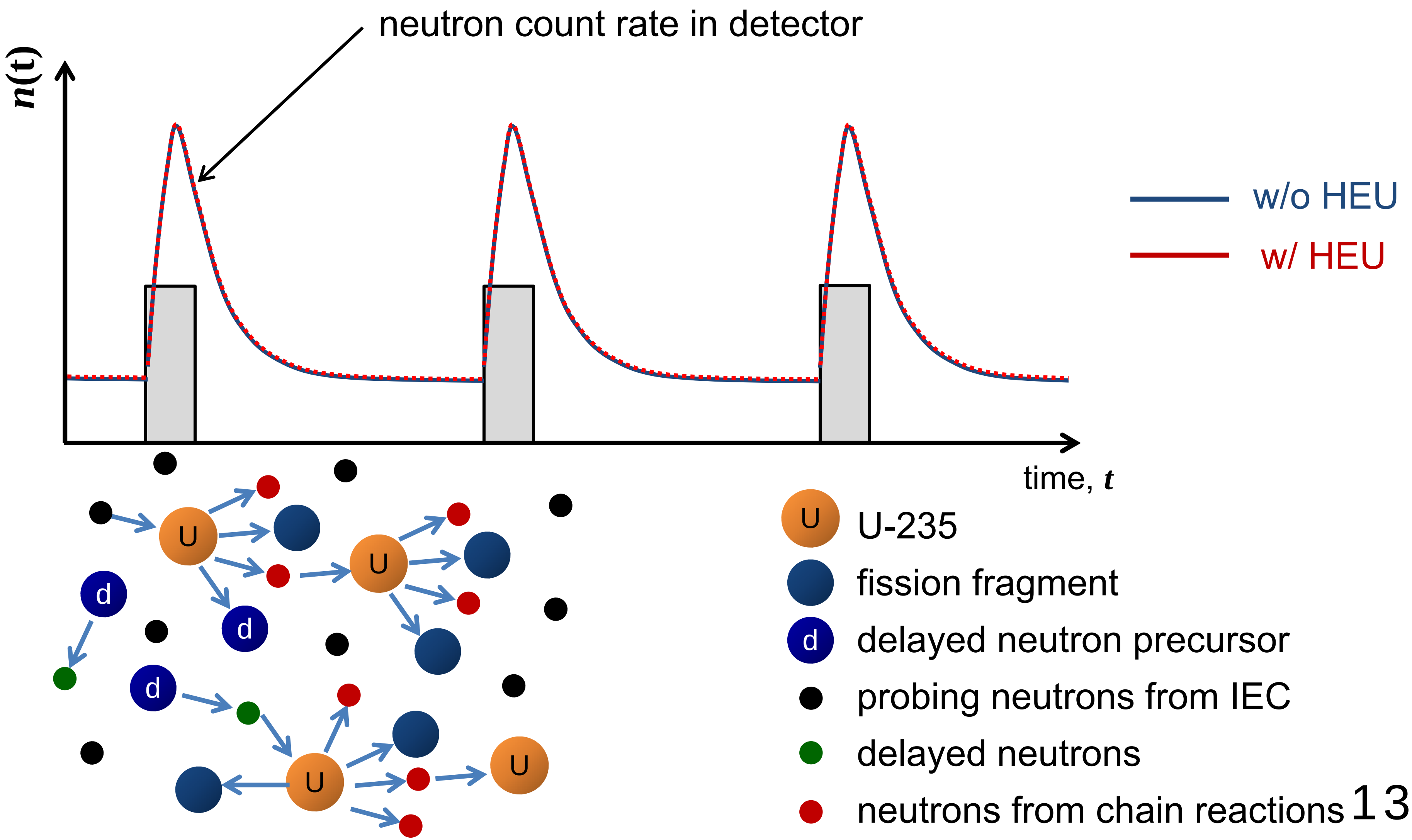
Delayed Neutron Noise Analysis (DNNA)



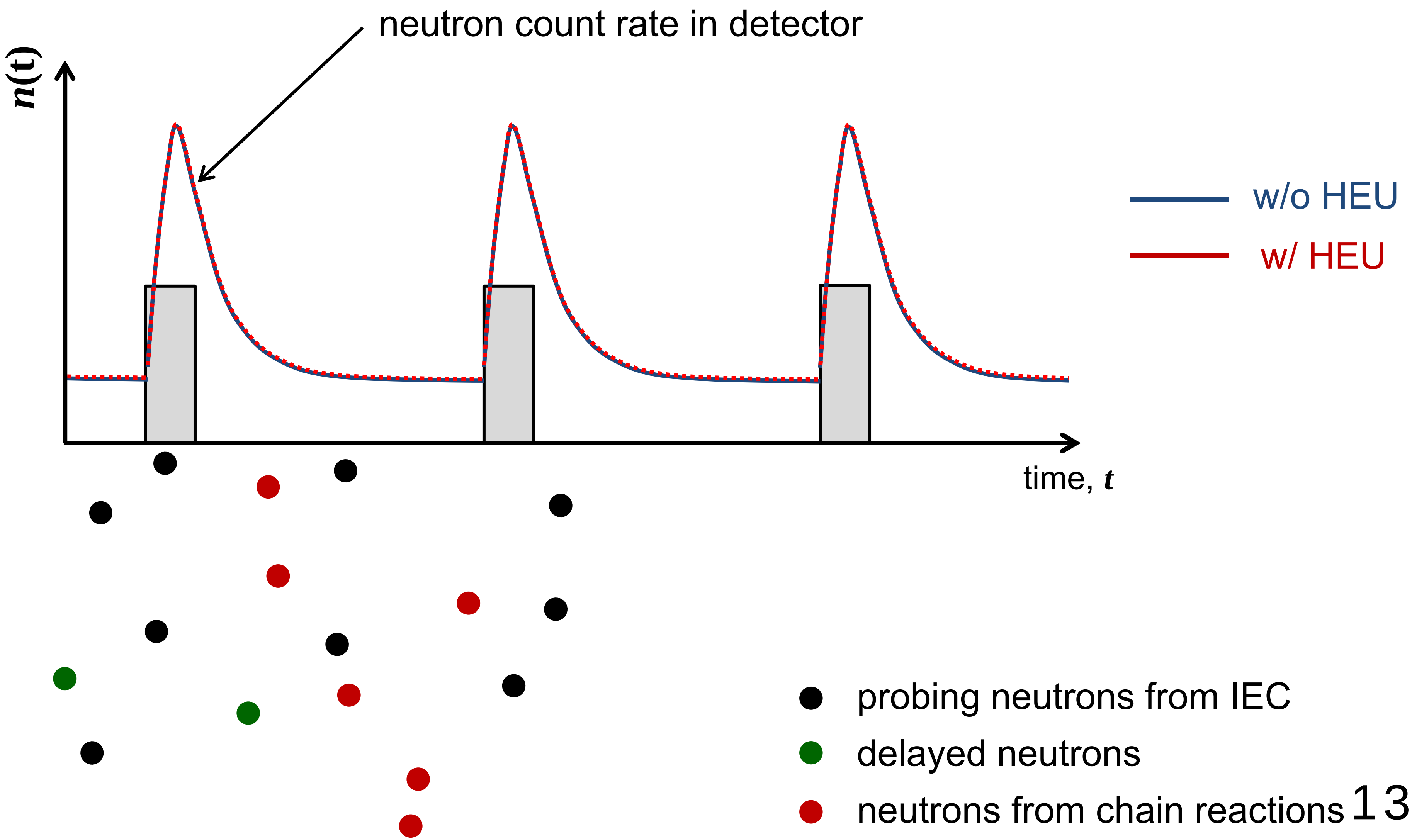
Delayed Neutron Noise Analysis (DNNA)



Delayed Neutron Noise Analysis (DNNA)



Delayed Neutron Noise Analysis (DNNA)

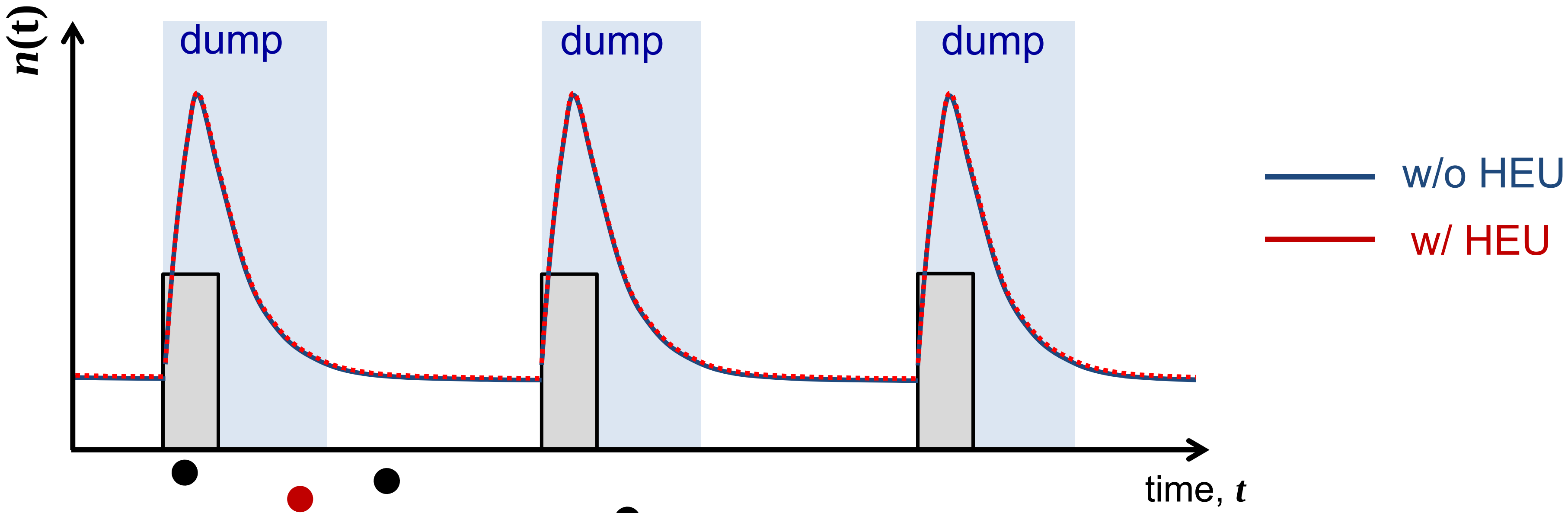


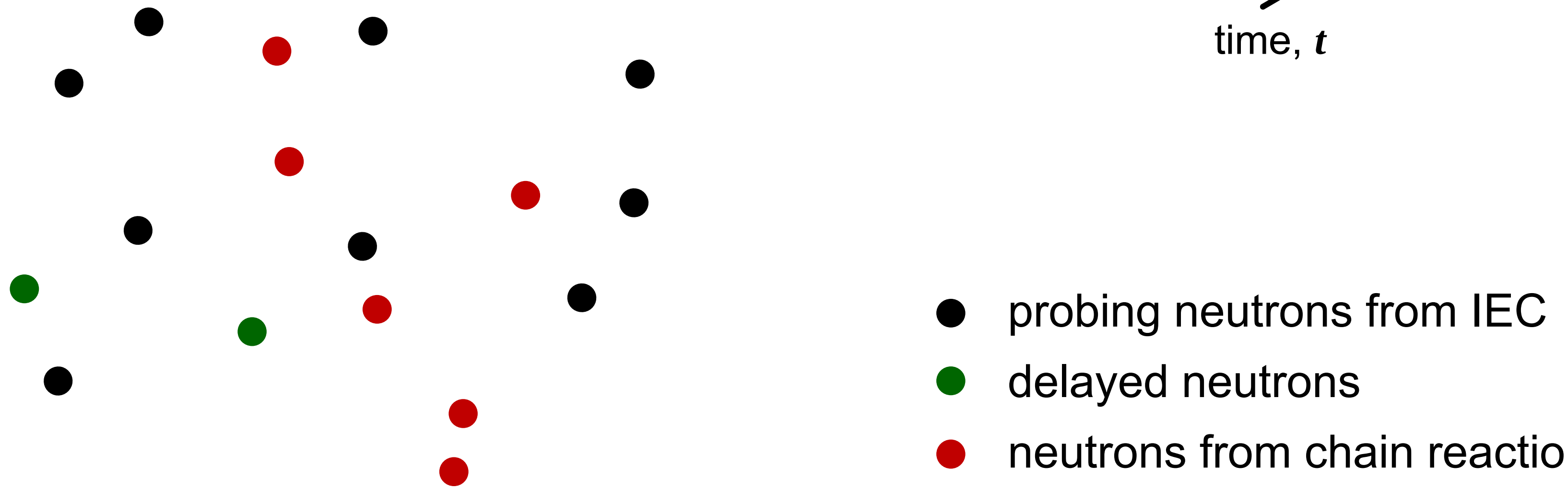
Delayed Neutron Noise Analysis (DNNA)

$$Y(t) = \frac{\sigma^2(t)}{\overline{n}(t)} - 1$$

$Y(\infty) = 0$ random neutrons (Poisson distribution)

$Y(\infty) > 0$ neutrons from fission chain reactions



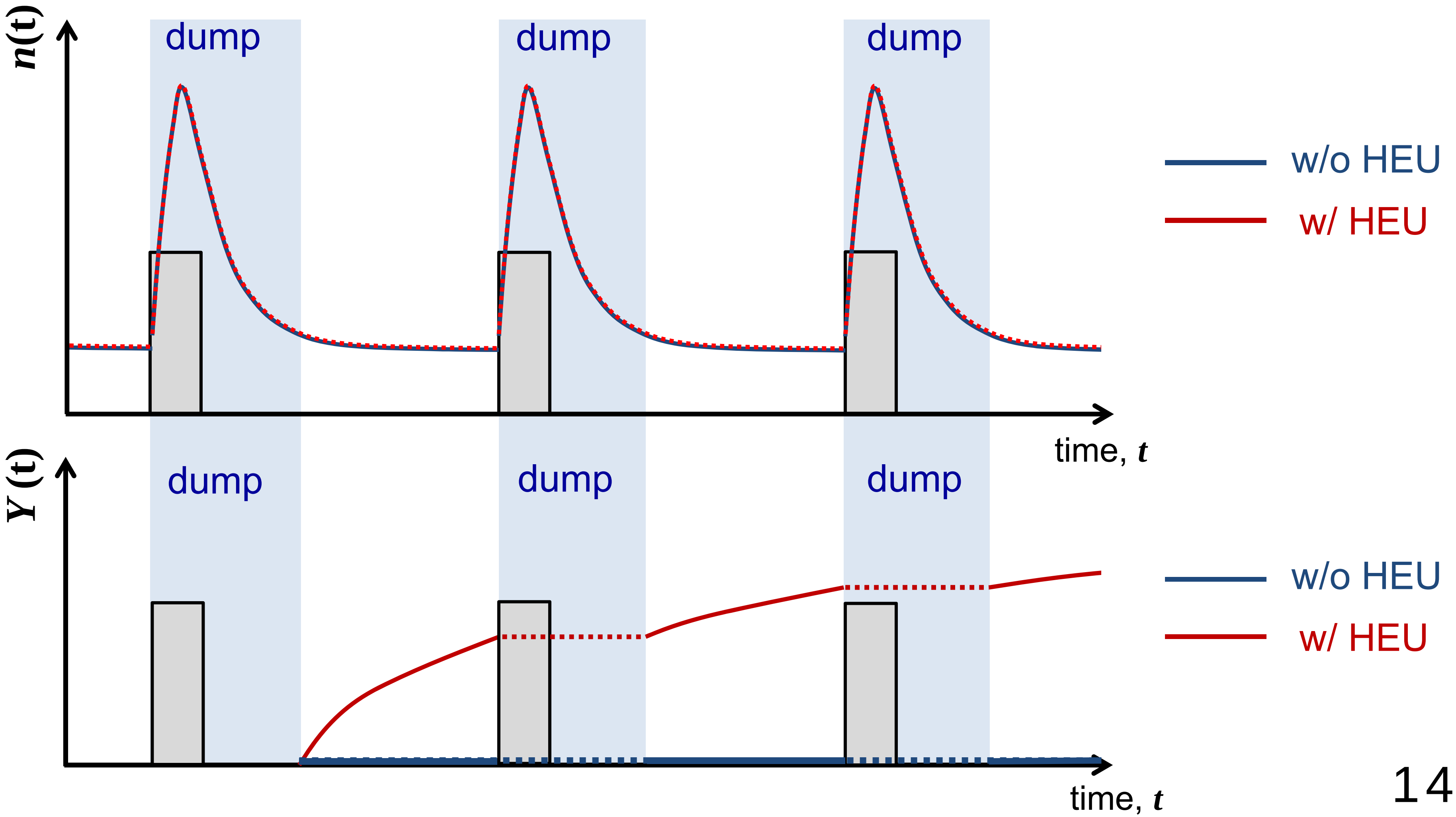


Delayed Neutron Noise Analysis (DNNA)

$$Y(t) = \frac{\sigma^2(t)}{\overline{n}(t)} - 1$$

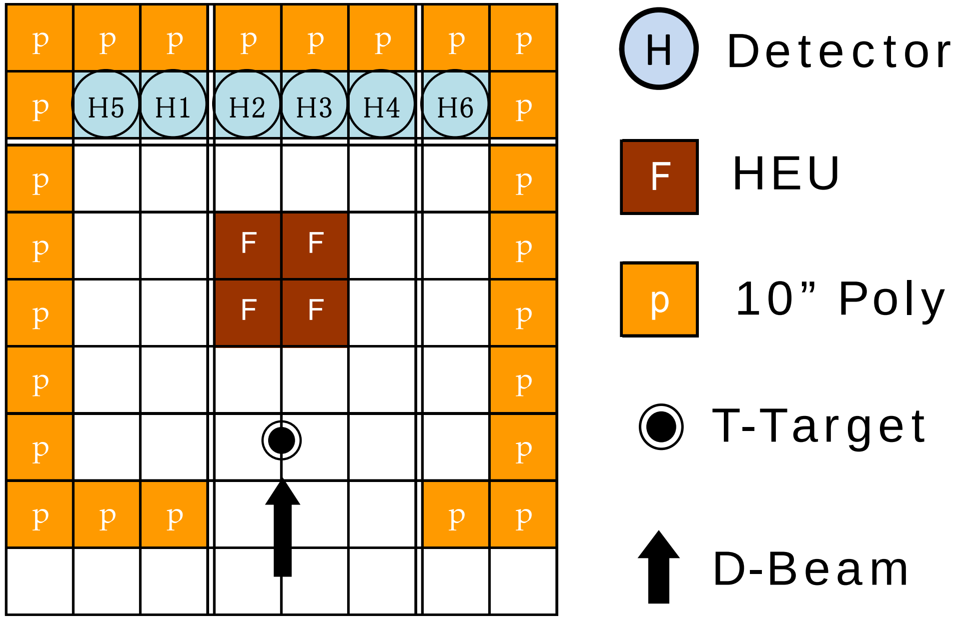
$Y(\infty) = 0$ random neutrons (Poisson distribution)

$Y(\infty) > 0$ neutrons from fission chain reactions



DNNA Experimental Setup in KUCA

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan



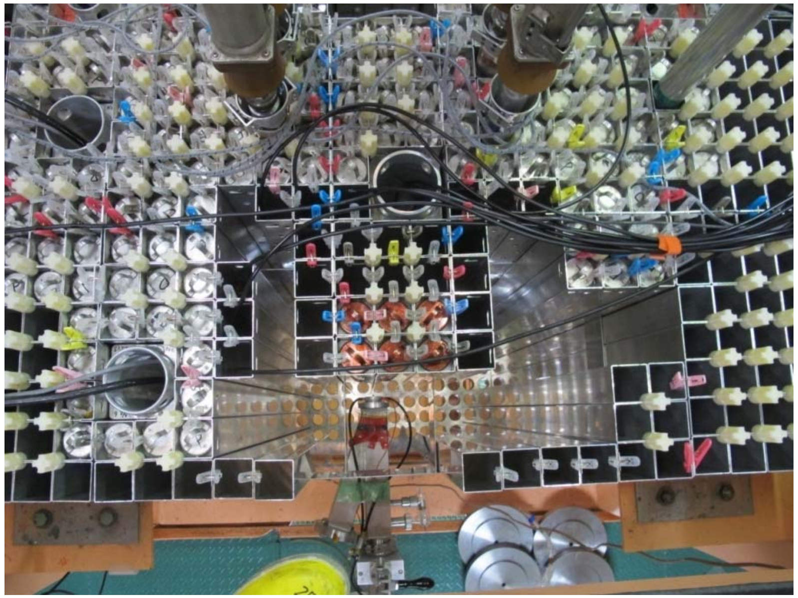
^{3}He: 1"dia., 20cmL, 5atm

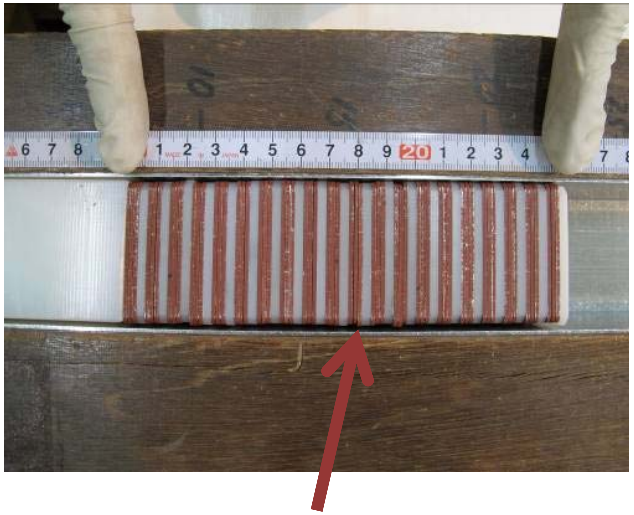
U-235 : 1.3 kg (k_{eff} = 0.12)

NPR (DT) : ~10^{5} n/sec

10 μsec, 10 Hz

ROI in DNNA: 50-100 msec

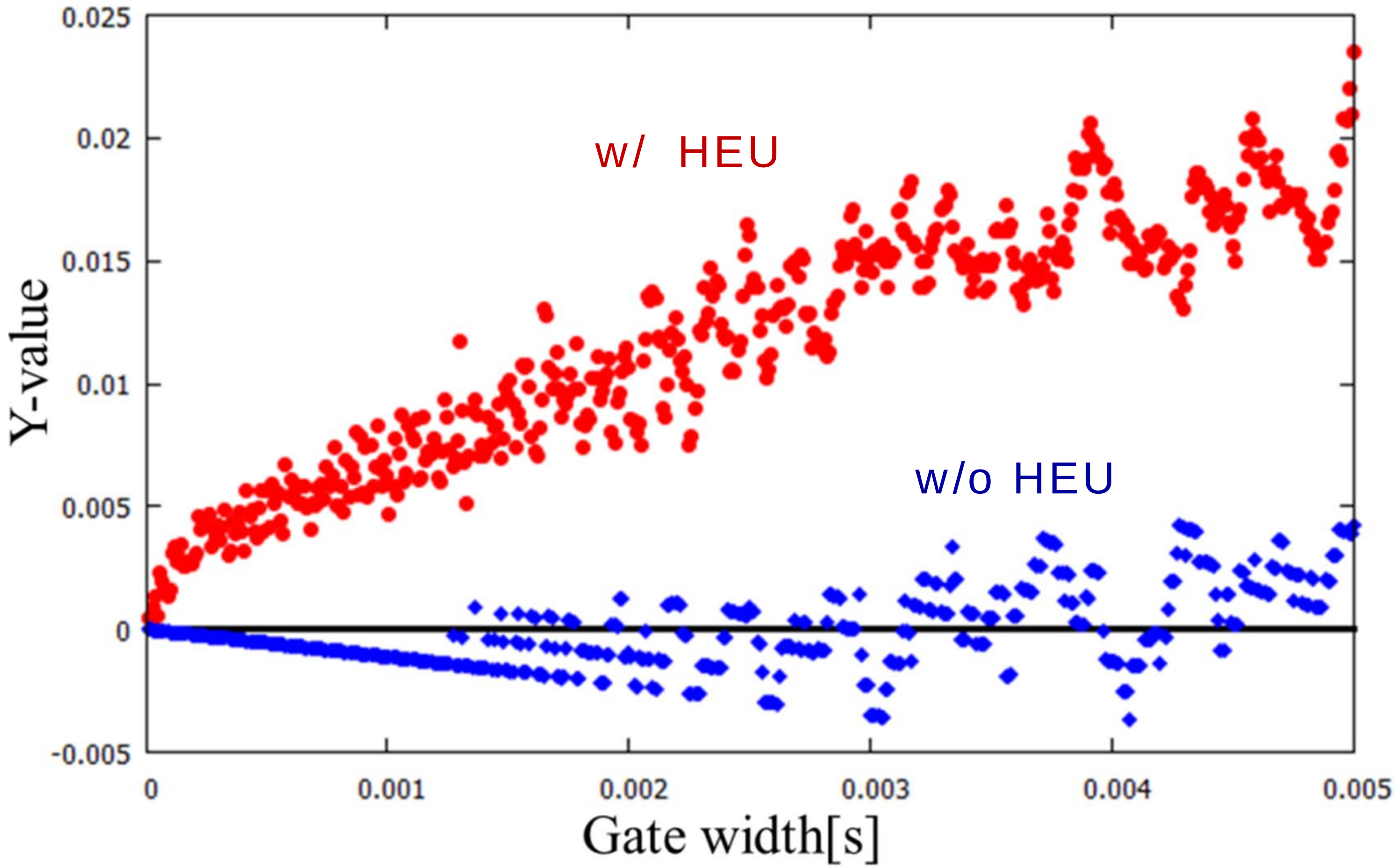




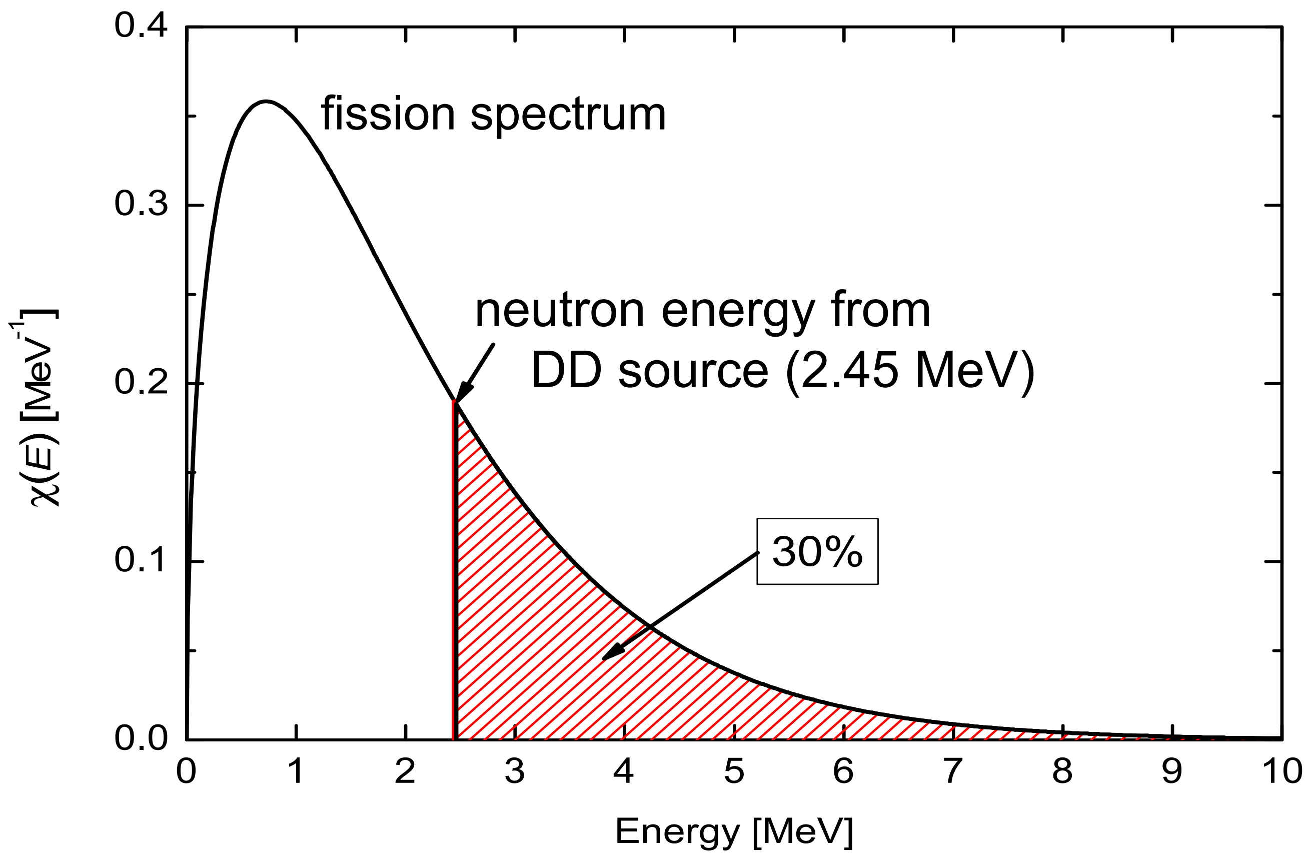
HEU

DNNA Experimental Results

- Clear difference in Y(t) was seen from BG w/o HEU.

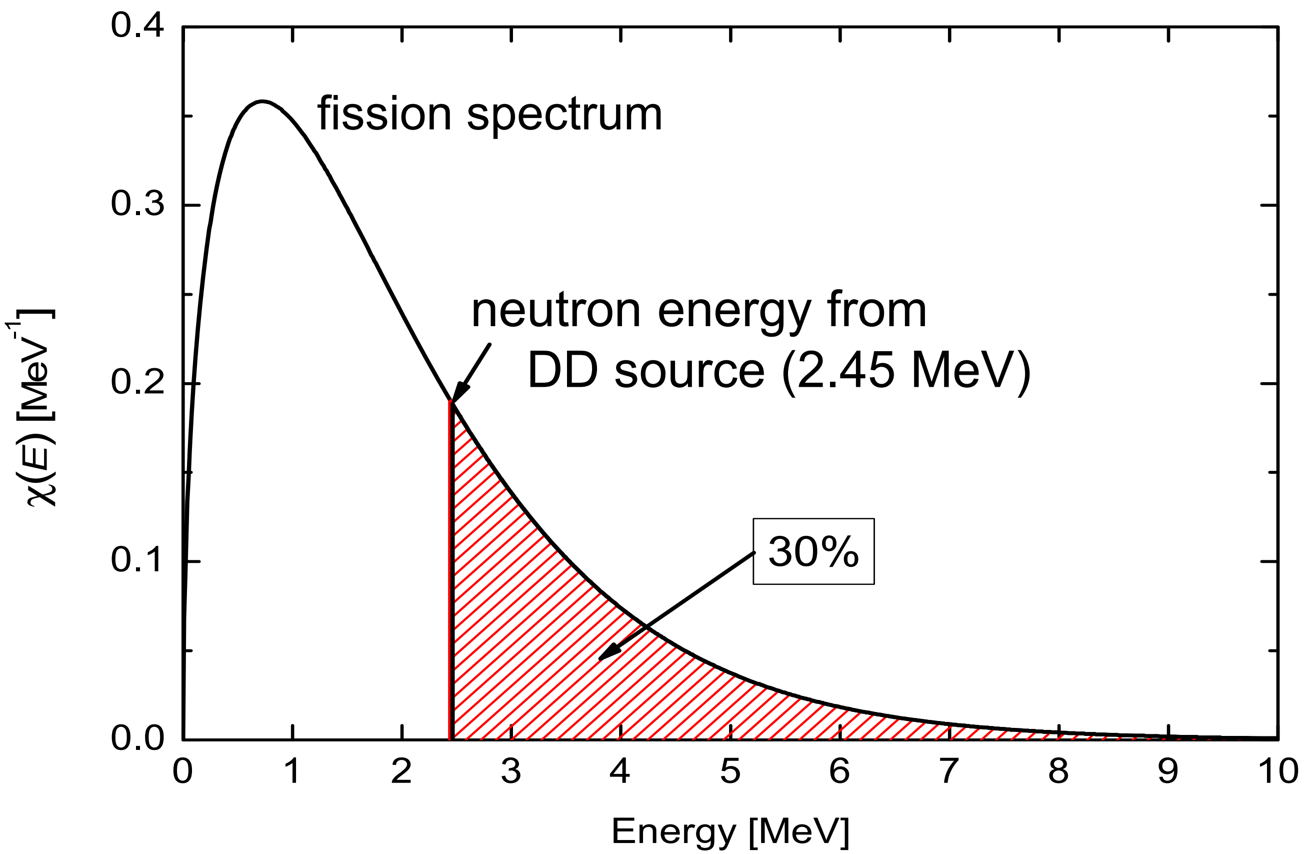


- A significant portion of the fission neutrons is above DD neutron energy.



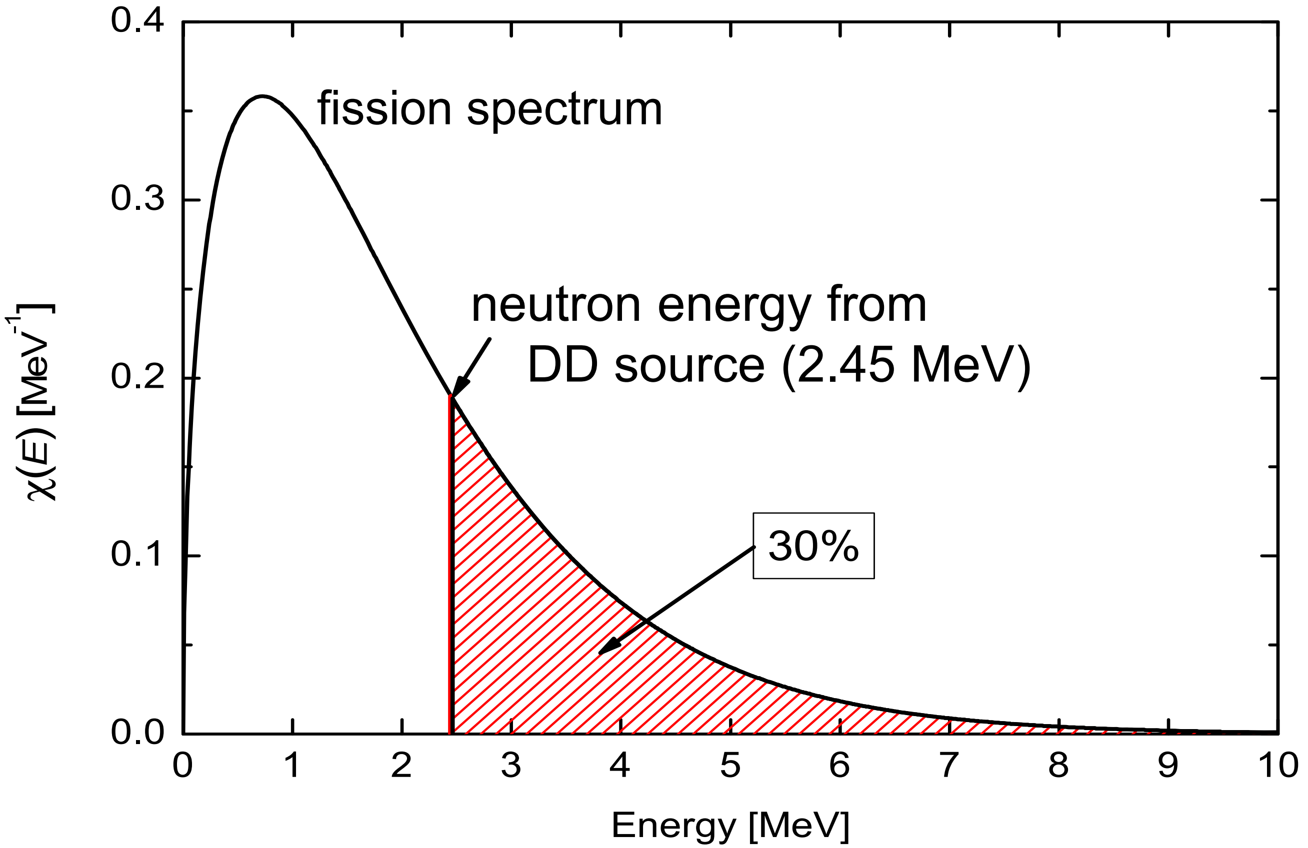
Threshold Energy Neutron Analysis (TENA)

- A significant portion of the fission neutrons is above DD neutron energy.
- Use of DD neutron source is mandatory. Neither DT nor RI source is applicable.



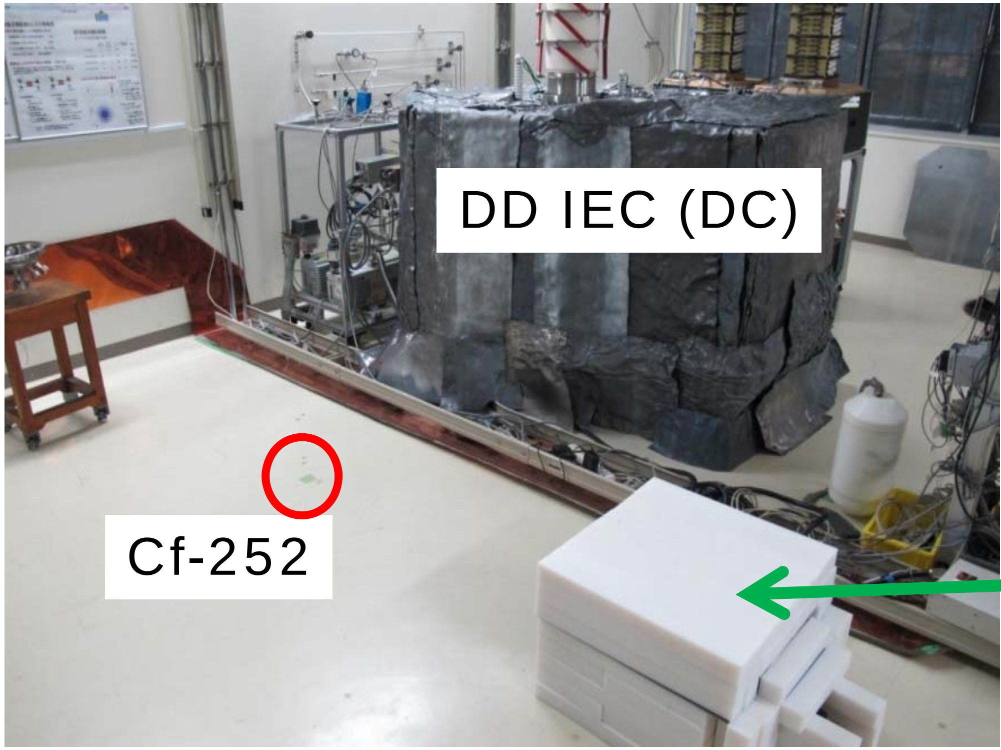
Threshold Energy Neutron Analysis (TENA)

- A significant portion of the fission neutrons is above DD neutron energy.
- Use of DD neutron source is mandatory. Neither DT nor RI source is applicable.
- Either dc or pulsed source is applicable.



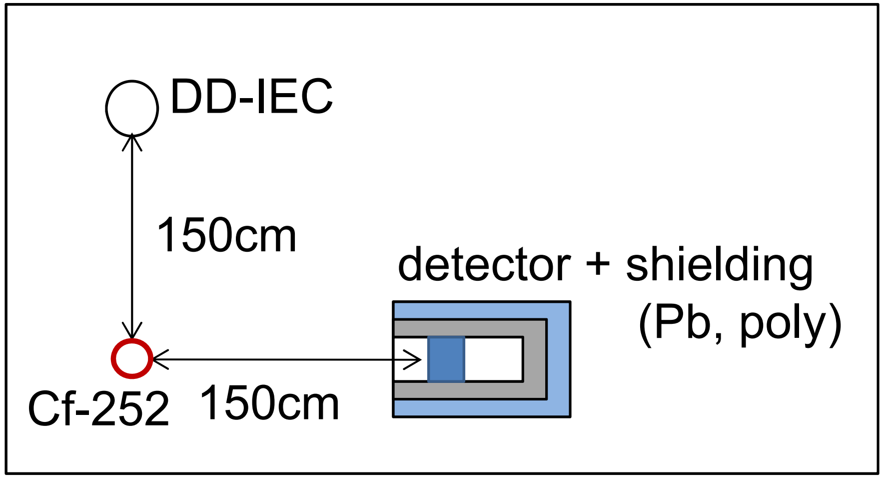
TENA Experimental Setup

Kai Masuda et al. "Active Interrogation of SNMs by use of IEC Fusion Neutron Source, IEC2013, Oct. 6-9, 2013, Kyoto, Japan



NE213 liquid scintillator
+ 5cm Pb + 10cm Ploy

X/γ-rays are rejected, making use of induced pulse shape difference.



DD IEC

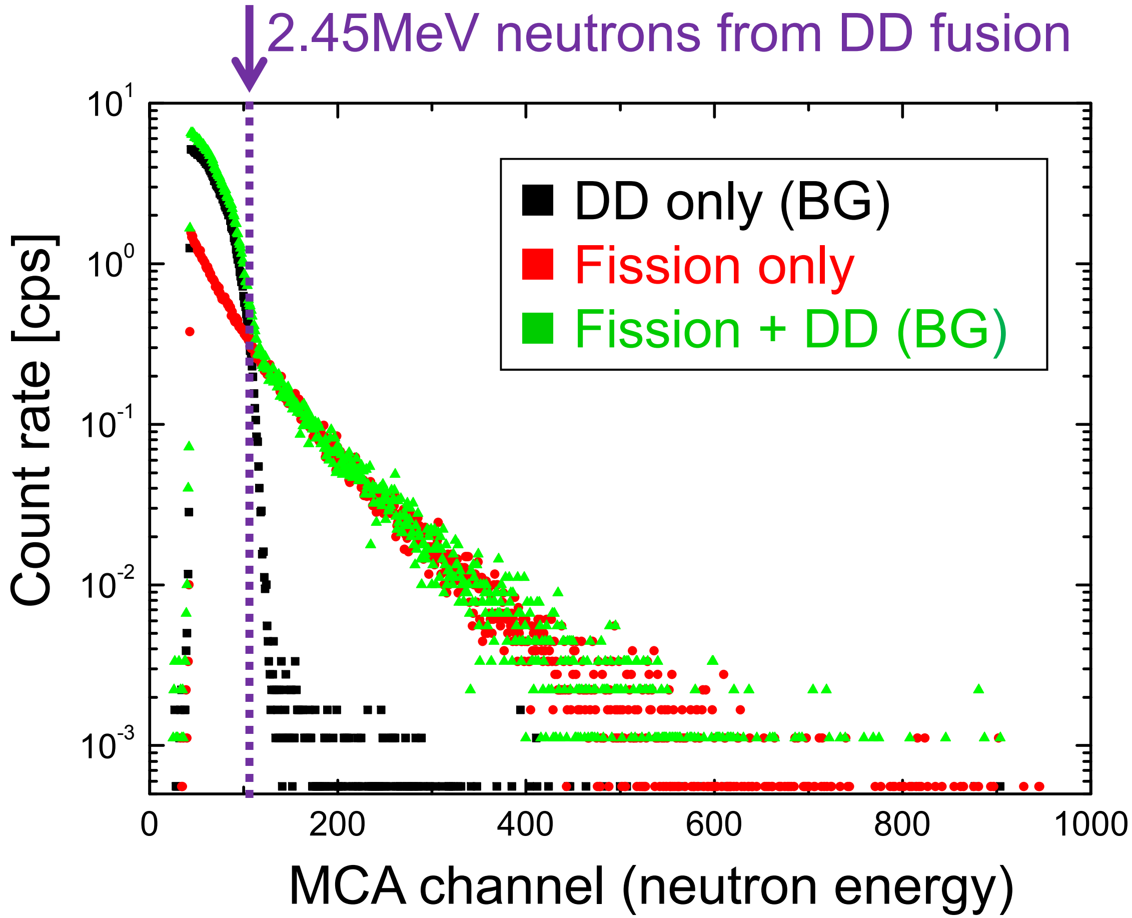
0.1, 1.0, 2.0, 3.0×10^7 [n/sec]

Cf-252

2.9×10^4 [n/sec]

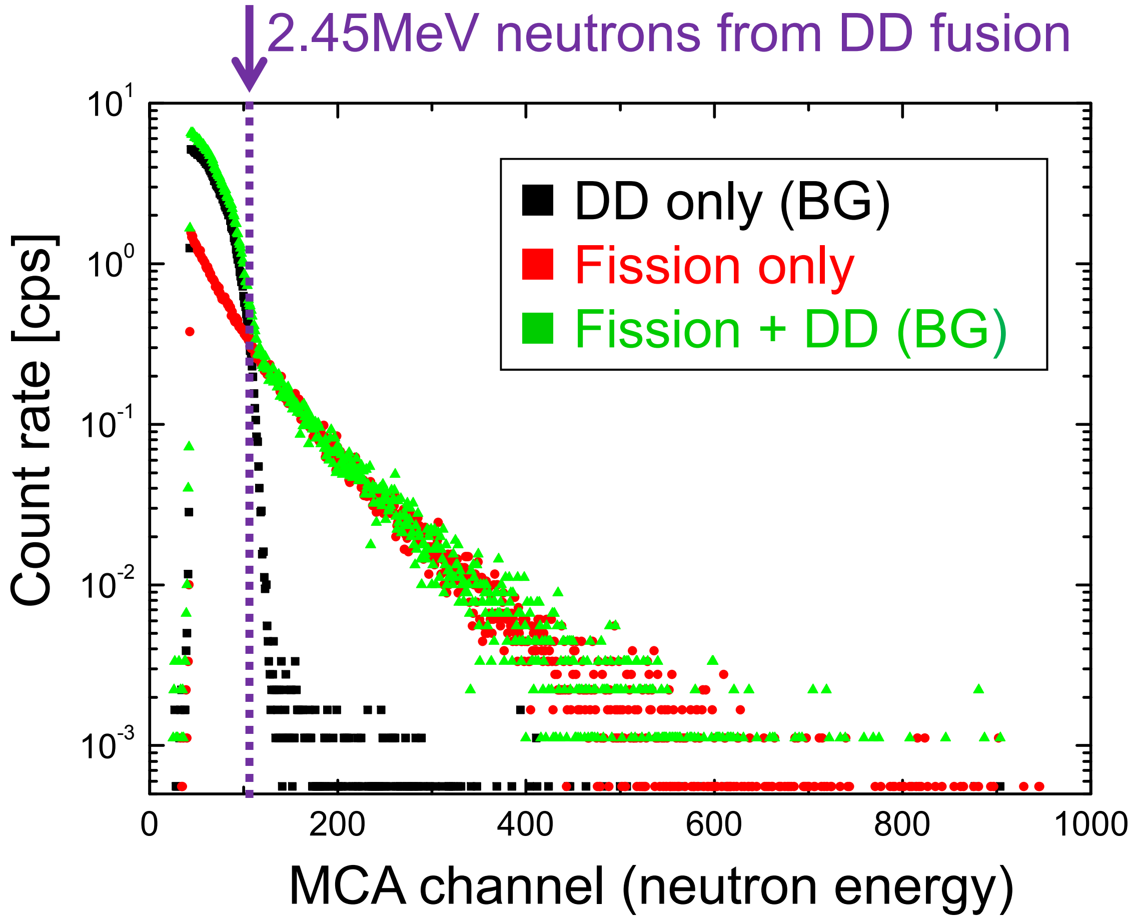
TENA Experimental Results

- Clear difference between Green (signal + BG) and Black (BG only) is seen above 2.45 MeV.



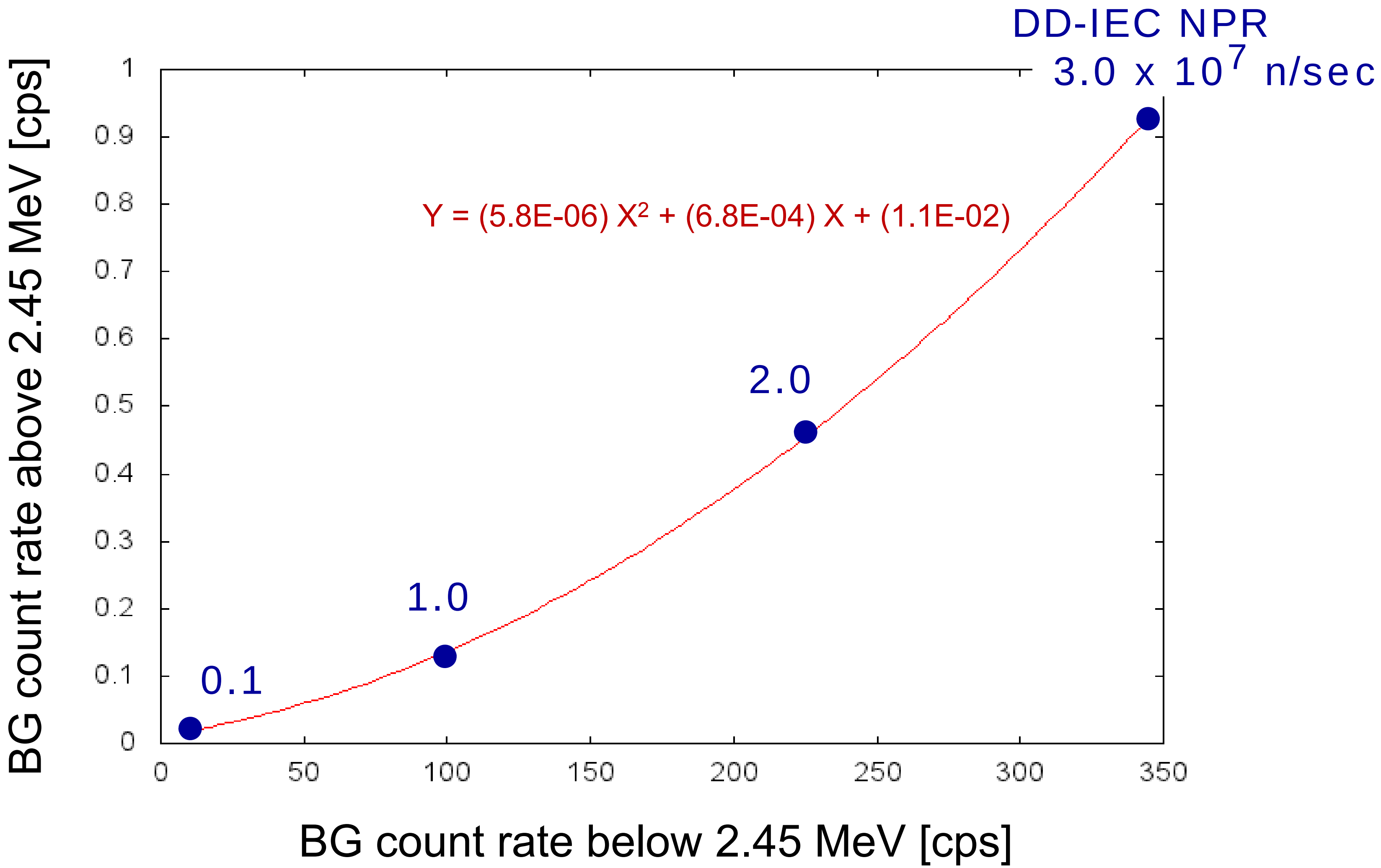
TENA Experimental Results

- Clear difference between Green (signal + BG) and Black (BG only) is seen above 2.45 MeV.
- BG counts above 2.45 MeV are seen due to X/γ-rays and pile-up of less energetic neutrons.



TENA Experimental Results (Contd.)

- BG count rate above 2.45 MeV is seen to increase nonlinearly as increase of incident DD neutrons (and X-rays) from IEC.

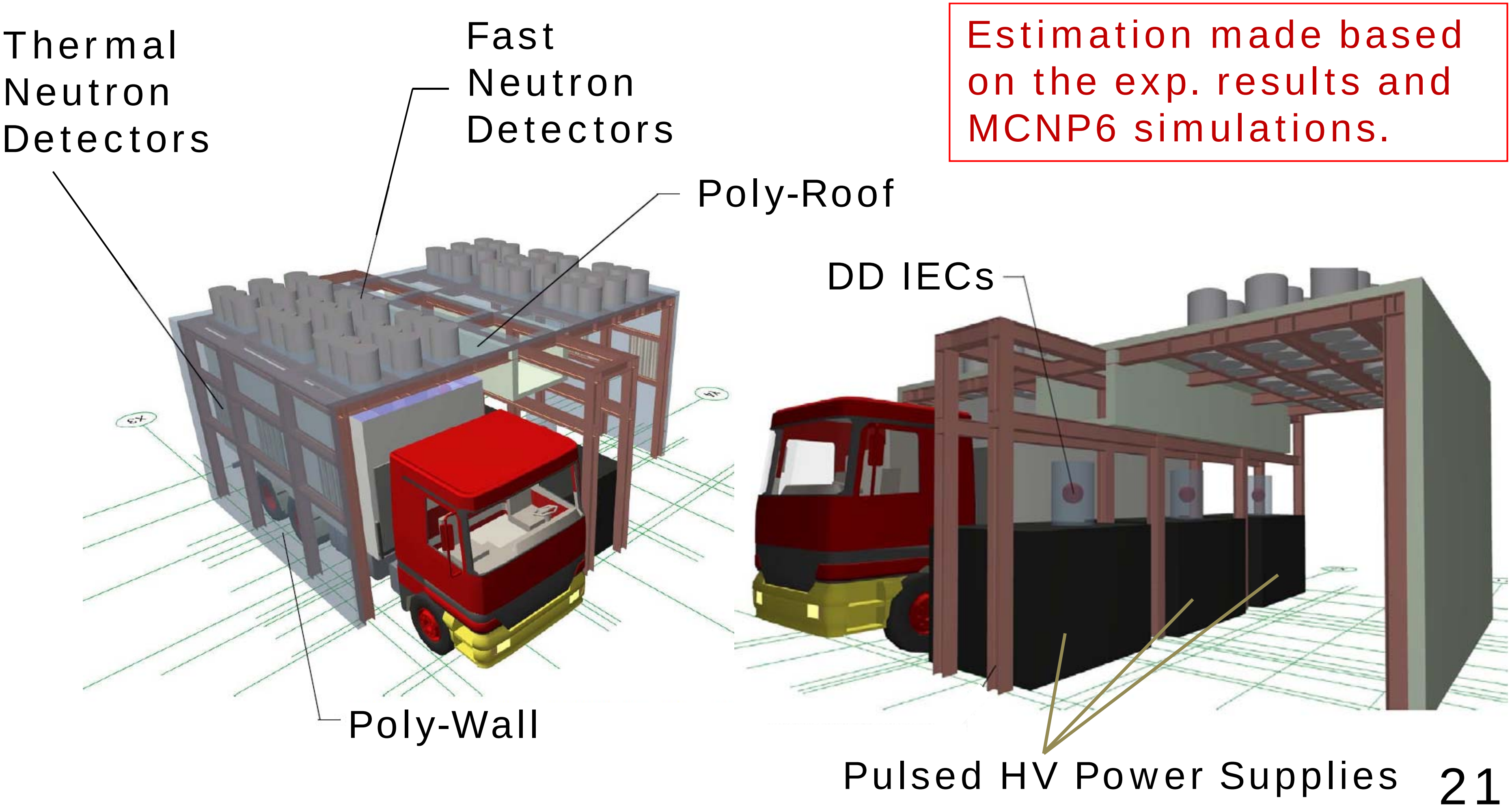


Estimation of Required Detection Time

Two container trucks are inspected simultaneously with

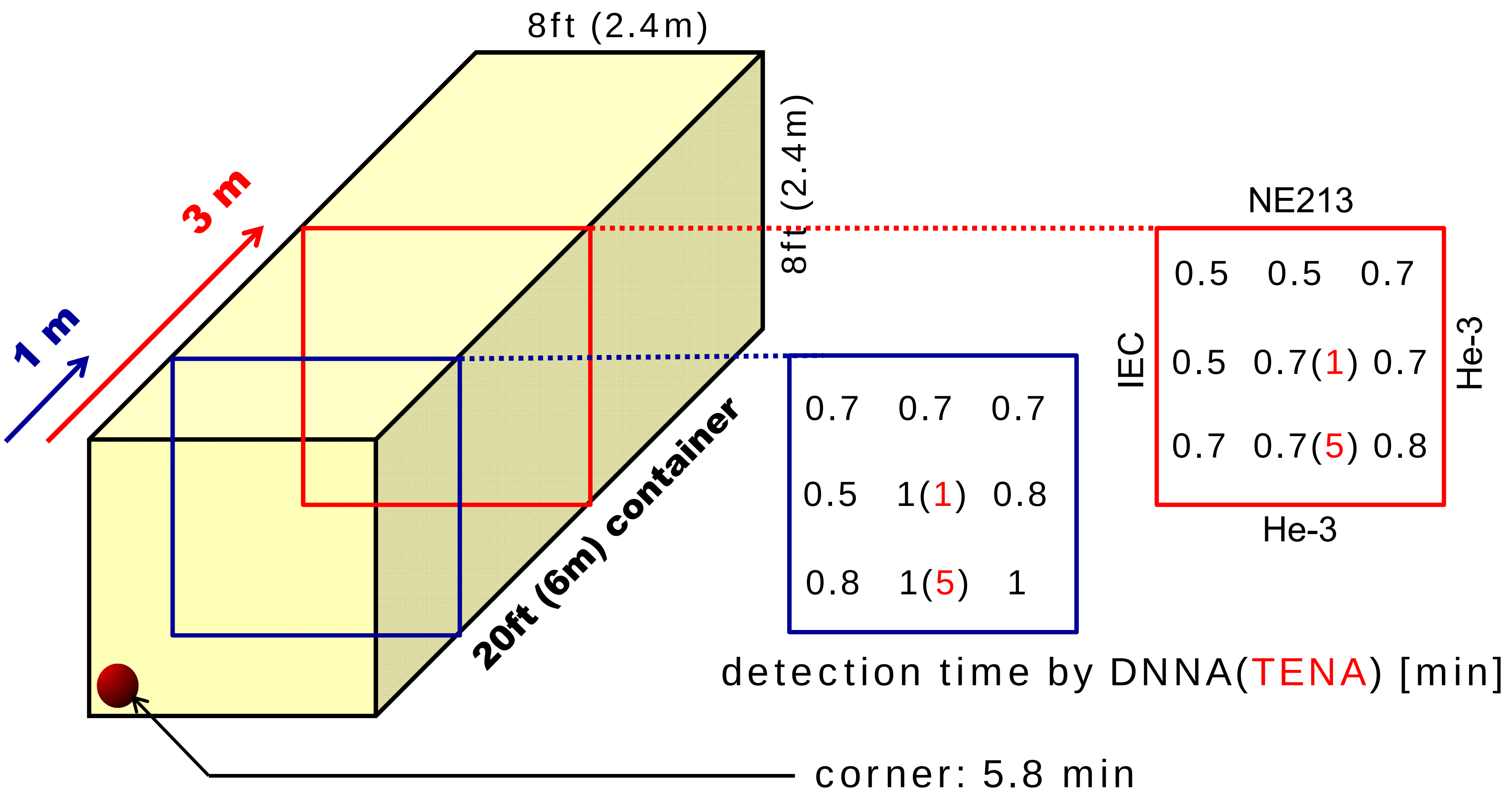
- Three pulsed DD-IECs (10^8 n/sec),
- 450 ^{3}He detectors (1" dia., 1m length), and
- 54 NE213 detectors (5" dia., 4" length).

Estimation made based on the exp. results and MCNP6 simulations.



Detection Time for 1kg HEU

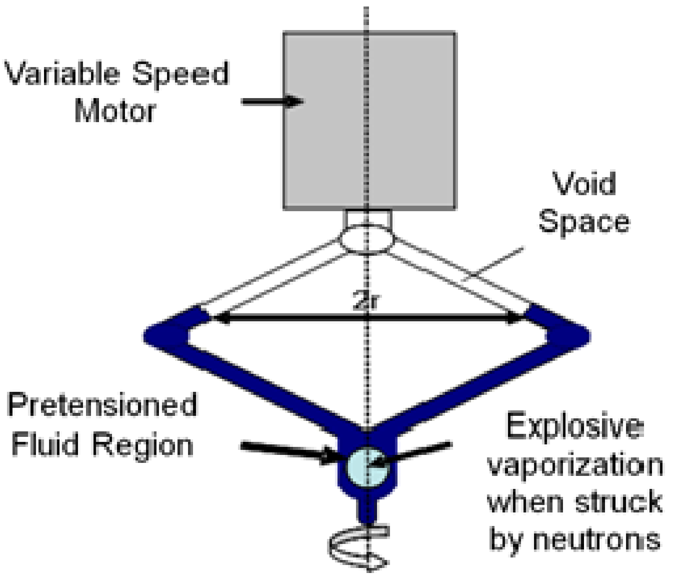
Assumption:
Nothing in the container except for 1-kg HEU.



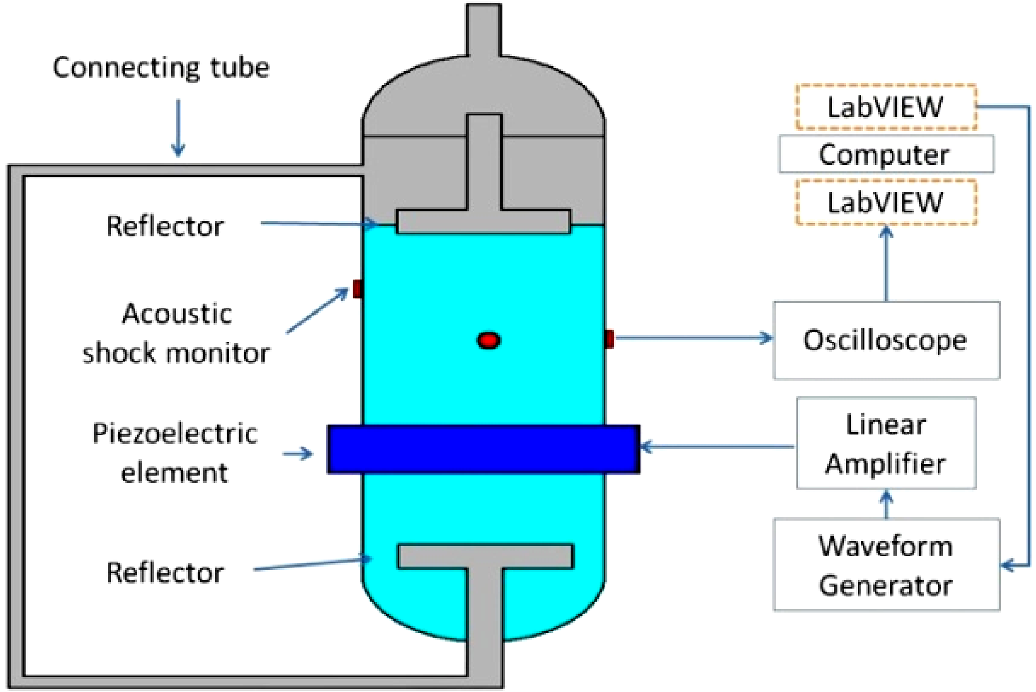
Tensioned Metastable Fluid Detector (TMFD)

Developed by Prof. Taleyarkhan' group in Purdue Univ. See for example, R.P. Taleyarkhan, et al., Nuclear Engineering and Design 238 (2008) 1820.

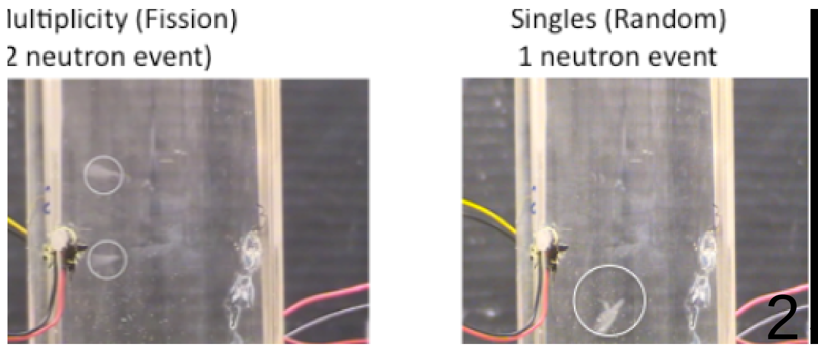
Centrifugal TMFD



Acoustic TMFD



- Blind to X/γ-rays.
- Blind to neutrons below a threshold energy.
- The threshold neutron energy variable.
- ~90% efficiency with 10cm x 10cm volume.
- Directional detection by ATMFD.



Concluding Summary & Plan

- Nondestructive screening as fast as 2 min/container is required in order not to block sea container distribution.
- Experiments have been made for the two neutron-based methods, namely DNNA and TENA.
- An inspection facility has been designed, which can handle two container trucks per 10 min, including mandatory 5 min for trucks replacement.
- 5'x5'x5'-scale tests are planed Dec 2014 – Feb 2015 by use of a single IEC, reduced number of detectors and U-235 (natural uranium).
- We also plan to test a novel fast neutron detector, TMFD, which is ideal for TENA because it is blind to X/γ-rays and neutrons below 2.45 MeV.