Results from U-235 Detection Experiments with an SNM Interrogation System Prototype Employing a Portable DD-IEC Neutron Source

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“CBRNe” threats

“Chemical”	e.g. sarin
“Biological”	e.g. basillus anthracis
“Radiological”	dirty bomb, radioactive substances
“Nuclear”	nuclear bomb, SNMs (U-235, Pu-239)
“explosive”	improvised explosives (IED)

Portable, transportable and stationary gate devices have been deployed in response to all hazard threats except “N” threat.

Detection of Shielded SNM

- SNM produces a relatively weak passive signature that can be easily shielded.
- Active (photon or neutron) interrogation techniques proposed so far for deployment in seaports typically require large and heavy systems.

Active neutron interrogation

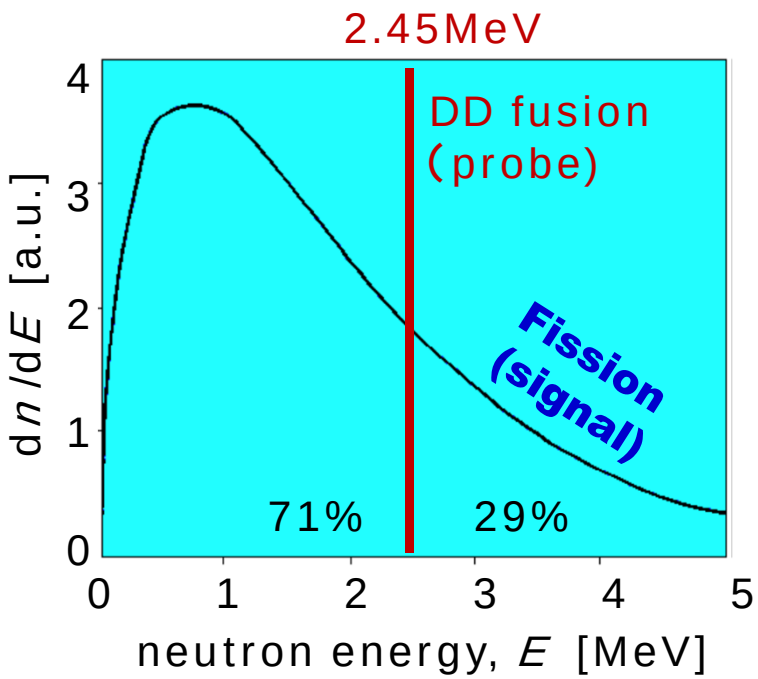
- Scanning a large volume (eg. sea container) is not a challenge, thanks to highly penetrating nature of thermal neutrons to induce fission.
- A principal challenge is to separate out probing neutrons from fission neutrons.
- Methods to cope with this task typically require highly intense pulsed source of neutrons, making it difficult to compose a portable on-site system.

We need to minimize
- neutron source intensity requirement, and
- size and weight of the system.

SNM detection principle

Threshold Energy Neutron Analysis (TENA)

- ✓ Use of DD is the key. Neither DT nor RI source is applicable.
- ✓ No need of pulsing the neutron source.



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

- Scattering makes the probing neutron energy lower.
- Unless SNM presents, no neutrons above the threshold.

BG sources seen in our earlier works using liquid organic scintillator are,

- ➢ Neutron-inducing gamma rays, and
- ➢ Pile-up of less energetic neutrons.

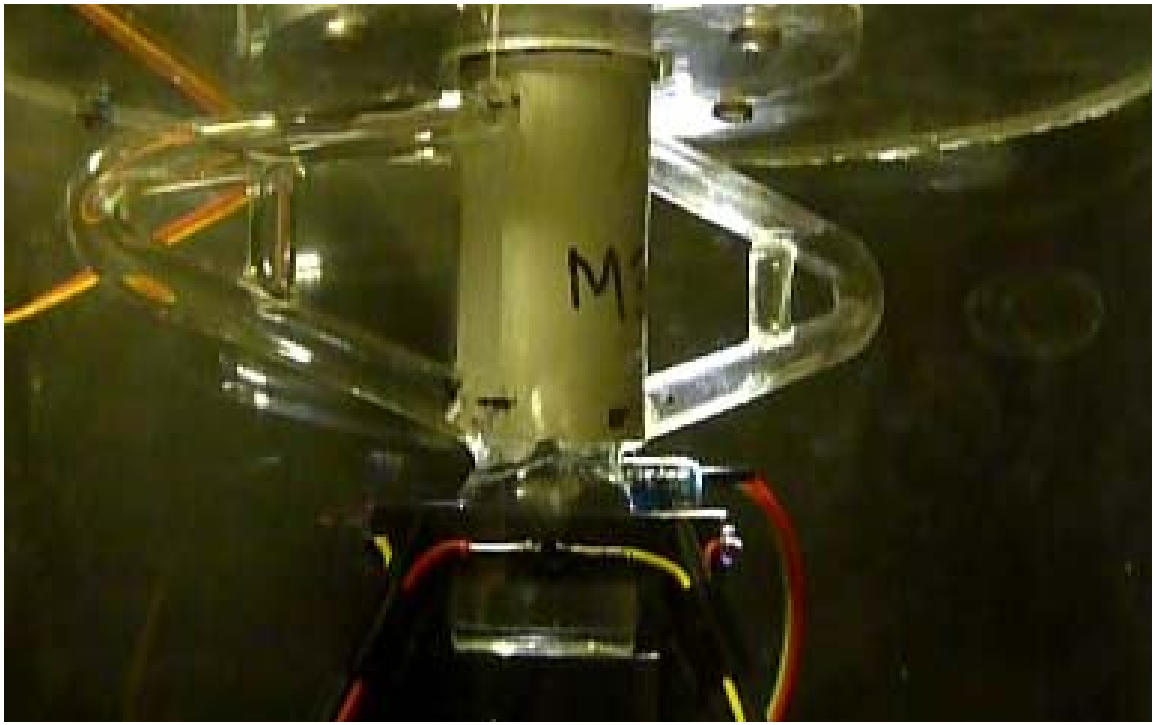
NE213+Pb+Poly+PSD

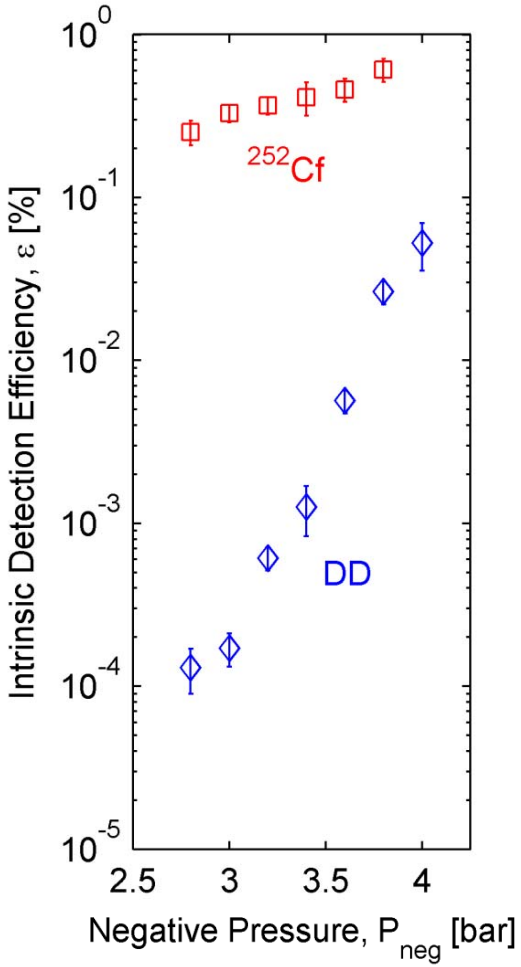
Fast neutron detector

Centrifugally Tensioned Metastable Fluid Detector (CTMFD)

rejects the probing neutrons and gamma-rays w/o shielding

- blind to neutrons below a threshold energy E_{th}
- E_{th} is tunable by means of tension, P_{neg}, induced by centrifugal force
- 100 % blind to gamma rays
- highly sensitive to neutrons above E_{th}





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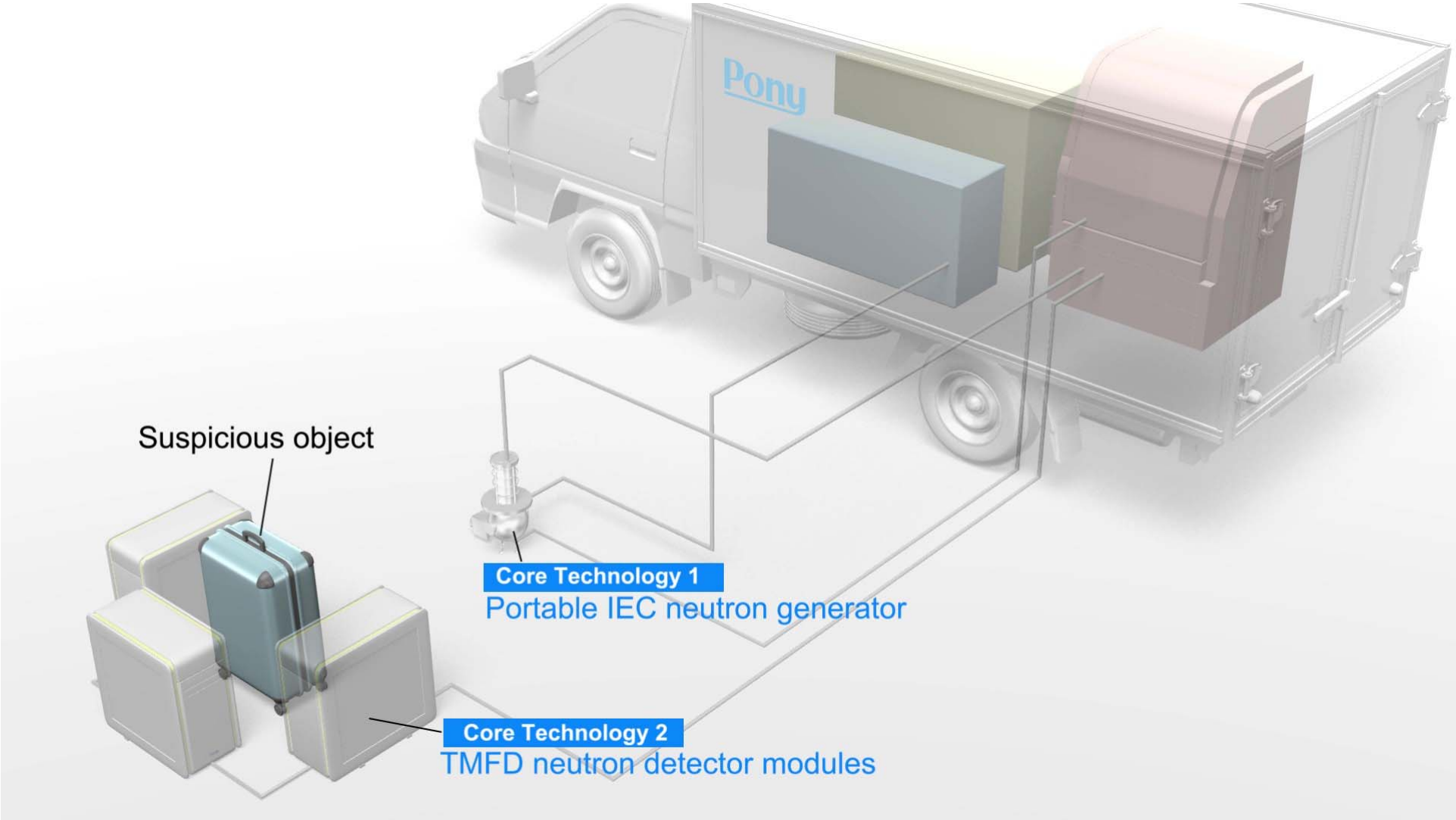
Overview of the proposed portable system

K. Masuda et al. "Results from U-235 Detection Experiments with an SNM Interrogation System Prototype Employing a Portable DD-IEC Neutron Source", 2018 US-J WS on IEC, MD, USA



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Prototype

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- Weight ~ 30 kg per module
- On-site setup time ~ 30 min
- Inspection time ~2 min @ 5e7n/sec

  no need of radiation shielding
  with 10 m evacuation zone

Glow discharge IEC
9e7 n/sec DD CW
Details by Dr. Bakr

Portable DD Neutron Source

LW-CTMFD (left)

50% reduction in weight
60% reduction in size
80% reduction in power consumption

Detector Array

9 LW-CTMFDs
No need of shielding to block BG

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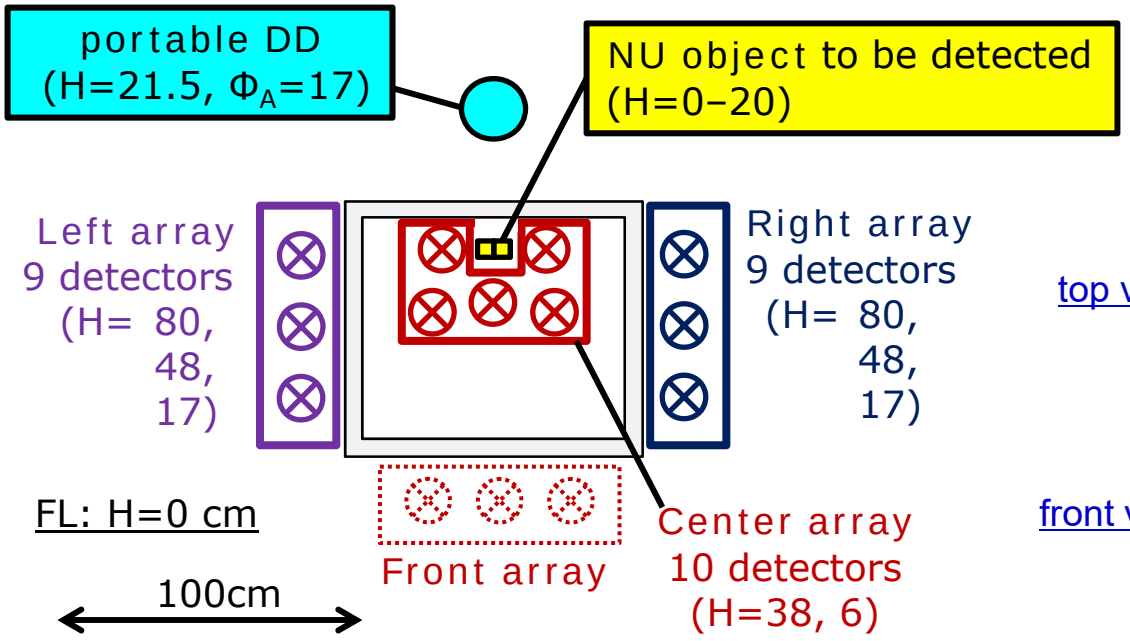
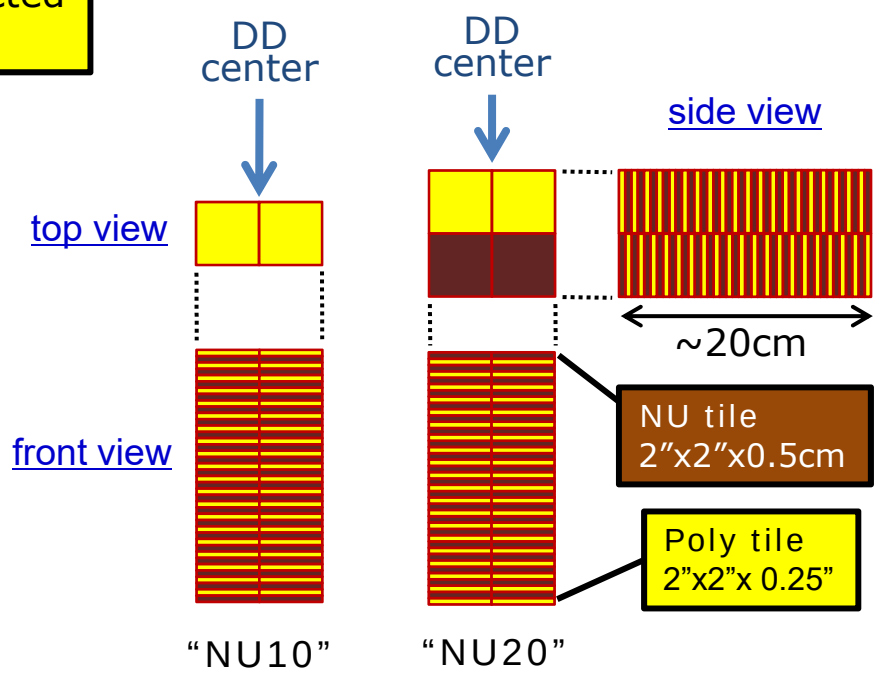
Experimental Layout





Layout

- Inspection volume: 0.8 x1.0 x1.0 m^3 cargo placed on the floor.
- Test done so far only for a specified simulant position in empty cargo.
- "Center" instead of "Front" array for study eg. distance dependence.

NU object to be detected

- Metal natural uranium tiles piled with polyethylene tiles.
- Both the "NU10" and "NU20" are ~20 cm in height.
- Placed on the floor.

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Experimental Conditions

number of runs

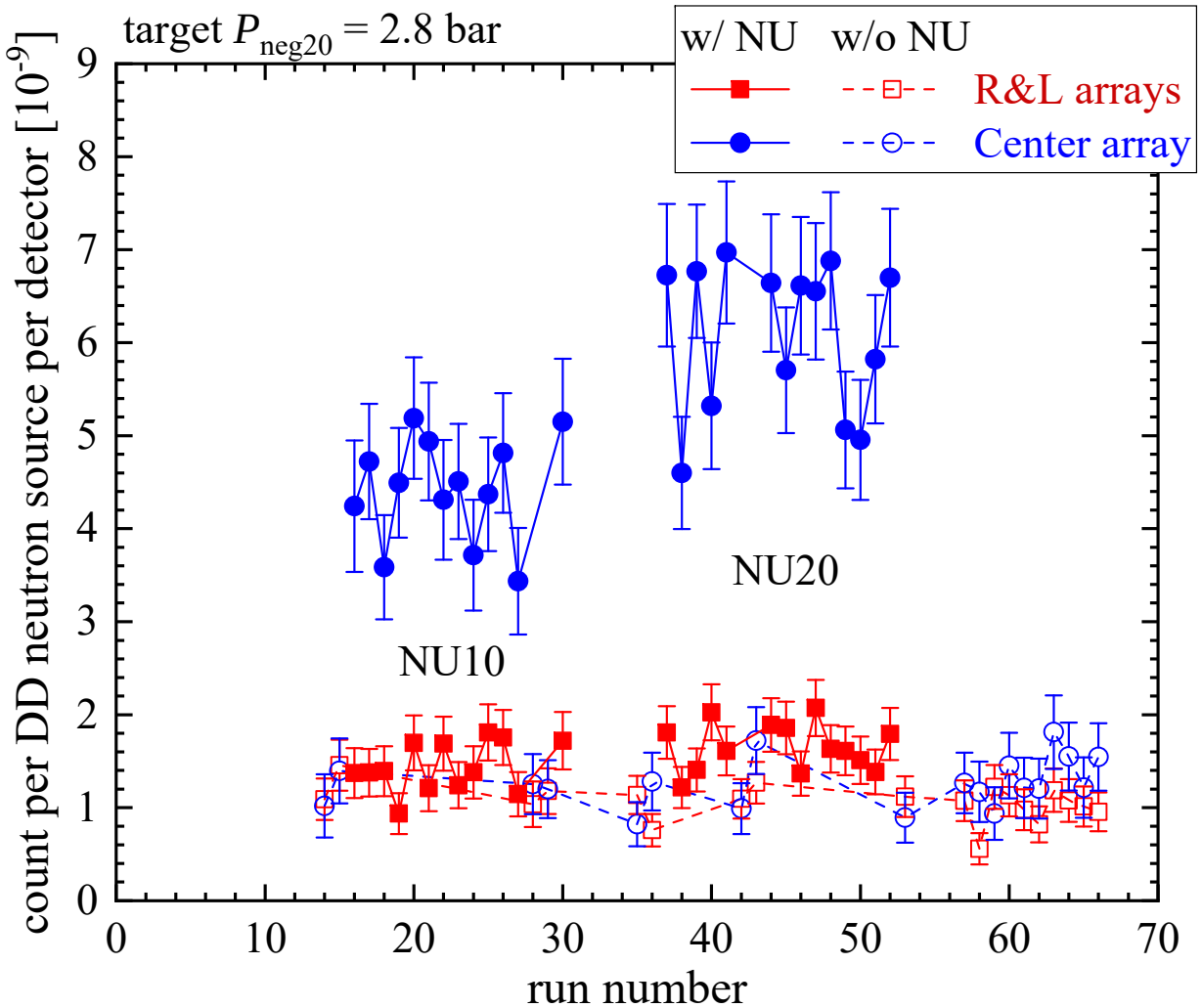
	P_{neg} [bar]	2.4	2.8	3.2	3.6
DD neutron source ~8e5 n/sec	w/o NU	4	20	7	1
	w/ NU10	—	13	—	—
	w/ NU20	10	14	—	—
Cf-252 source ~2e4 or 8e4 n/sec		3	4	3	—
BG w/o neutron source		—	11	—	—

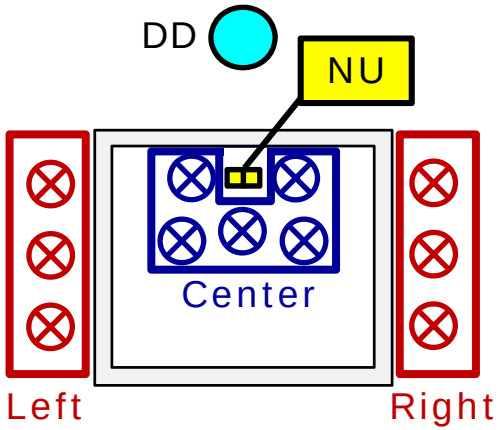
- DD source was operated at a very low intensity <1e6 n/sec, the radiation hazard control regulation for the experimental room.
- Each run duration was mostly 30 min. 15 or 60 min in some cases.
- First P_{neg} was scanned, and then fixed at 2.8 bar.

Experimental Results

Run-by-run variation and trend

- Only runs with DD source and at Pneg =2.8 bar are shown below.



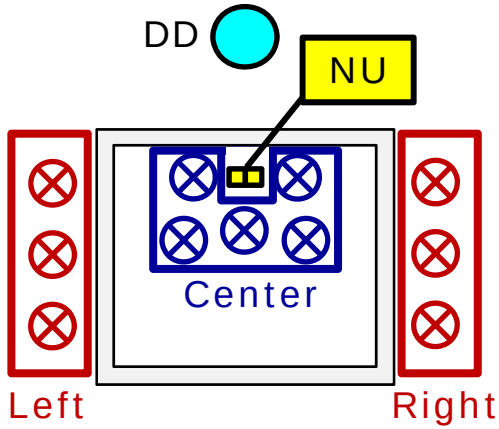


Experimental Results (contd.)

Accumulated count per accumulated live time over runs

count rate per detector [cph]

	Center	R & L
BG, $\dot{n}_{BG}$	1.6±0.2	1.5±0.1
w/o NU, $\dot{n}_{00}$	3.9±0.2	3.3±0.2
NU10, $\dot{n}_{10}$	13.2±0.5	4.3±0.2
NU20, $\dot{n}_{20}$	19.0±0.6	5.1±0.2
$\dot{n}_{BG}$ / $\dot{n}_{00}$	0.40±0.05	0.46±0.05



- Shown in the table are 68% confidence interval (1σ statistical error) on assumption of Gaussian distribution.
- ➢ $\dot{n}_{00} < \dot{n}_{10} < \dot{n}_{20}$ tendency is seen also in "R&L".
- ➢ Passive BG fraction is ~0.4, comparable with the rest, i.e. active BG.
- ➢ Note that DD source intensity, $\dot{n}_{DD}$, was at ~1/60 of the nominal. When operated at x60 higher $\dot{n}_{DD}$, active BG would be dominant, since $\dot{n}_{00} = \underbrace{\dot{n}_{BG}}_{\text{passive BG}} + \underbrace{\eta_{00}\,\dot{n}_{DD}}_{\text{active BG}}$

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Experimental Results (contd.)

Count per DD neutron source

$$\eta = \frac{\dot{n} - \dot{n}_{BG}}{\dot{n}_{DD}}$$

$\dot{n}$: count rate
$\dot{n}_{BG}$: count rate w/o DD source, i.e. passive BG
$\dot{n}_{DD}$: neutron production rate by the DD source

count per DD source [10^{-9}]

	Center	R & L
w/o NU, η_{00}	0.75±0.10	0.58±0.07
NU10, η_{10}	3.91±0.19	0.93±0.09
NU20, η_{20}	5.58±0.20	1.16±0.08

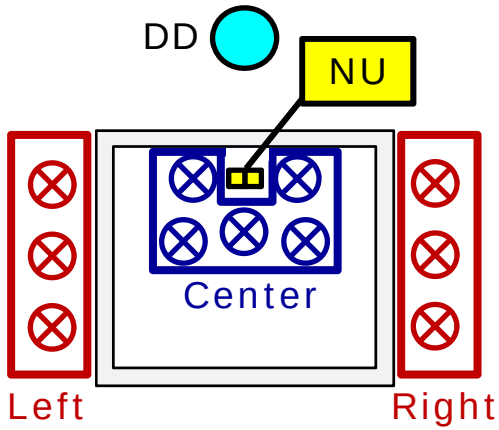
fission count per DD source [10^{-9}]

	Center	R & L
NU10, $\eta_{10} - \eta_{00}$	3.2±0.2	0.35±0.11
NU20, $\eta_{20} - \eta_{00}$	4.8±0.2	0.58±0.11
NU20 / NU10	1.5±0.1	1.7±0.6

C / (R&L) ratio
9.0±2.9
8.3±1.6

Fission count per DD source (see left bottom table)

- C to (R&L) ratio for both NU10 & NU20 agrees to the geometrical ratio of 7.9 (avg. distance square) .
- NU20 to NU10 ratio for "C" array is seen clearly less than two, i.e. not doubled by doubled amount of NU.
- This is not clear in "R&L" because of poor statistics.



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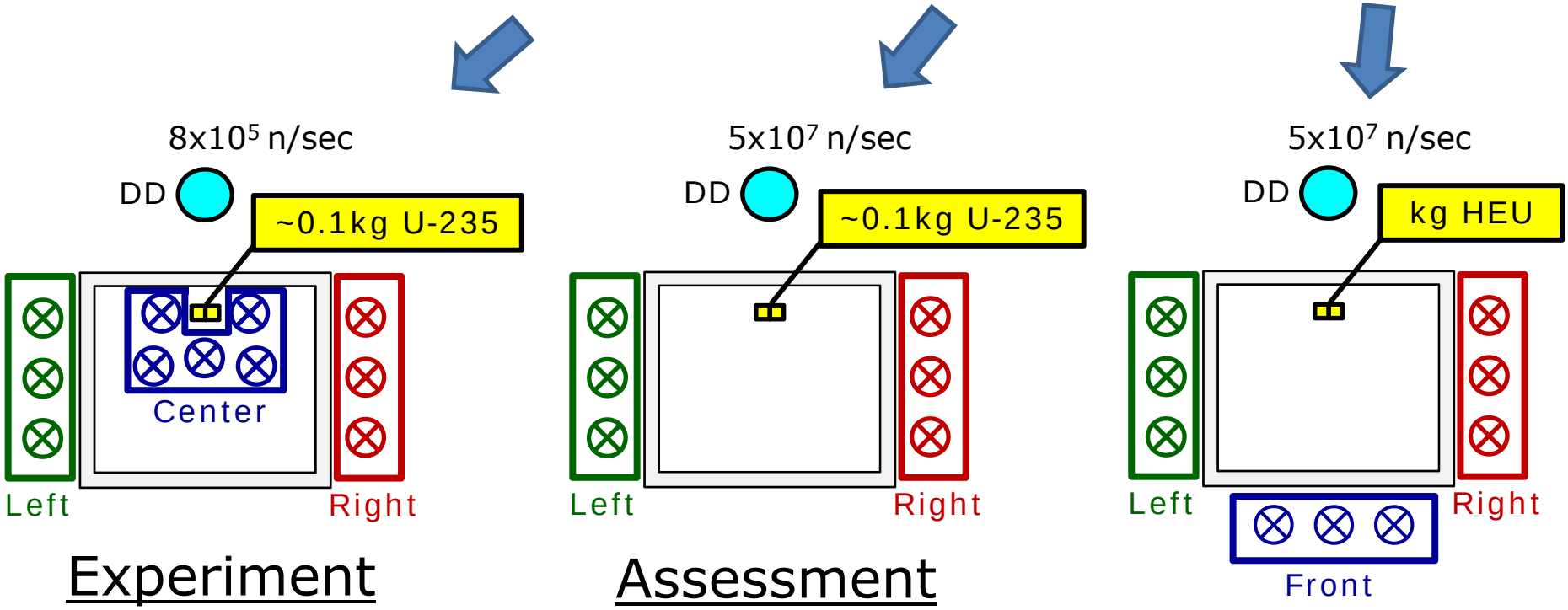
Detection Capability Assessment

K. Masuda et al. "Results from U-235 Detection Experiments with an SNM Interrogation System Prototype Employing a Portable DD-IEC Neutron Source", 2018 US-J WS on IEC, MD, USA

Condition	Experiment	Assessment	The Nominal
DD source intensity [n/sec]	8e5	5e7	5e7 (8e7 achieved)
Inspection time	30min x tens trials	90 sec	90 sec
Detector array	Right, Left, Center	Right, Left	Right, Left, Front
Object to be detected	"NU10", "NU20"	"NU10", "NU20"	1 kg HEU or equiv.



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Assessment flow

0. We assume that the count, *N,* follows a Poisson distribution.

1. The mean count, $N^{(mean)}$, of the assumed Poisson distribution is determined from $N^{(exp)}$ based on the experimental $\dot{n}_{BG}$ and η and their 1σ statistical error as follows.
   A) w/o NU: $N^{(mean)} = N^{(exp)} + 0.47\ \sigma(N^{(exp)})$ i.e. upper limit for 68% probability
   B) w/ NU: $N^{(mean)} = N^{(exp)} - 0.47\ \sigma(N^{(exp)})$ i.e. lower limit for 68% probability

2. Using 1A, detection threshold count, $N^{(th)}$, is determined so that PFA <5%.

3. Using 1B, PD is calculated based on the $N^{(th)}$ determined at step 2.

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Assessment Results

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Object to be detected	"NU10", "NU20"	"NU10", "NU20"	1 kg HEU or equiv.

Performance	Assessment		ANSI standard #
Object to be detected	"NU10"	"NU20"	5 kg LEU
U-235 amount	71 g	142 g	975 g
Inspection time	90±4sec	90±3sec	90 sec
PD at 68% confidence level	>74.2 %	>97.8 %	>90 %
PFA at 68% confidence level	< 3.8 %	< 3.6 %	< 5 %

IEEE ANSI N42.41-2007, Category A

- The evaluated detection capability for "NU20" meets the requirements.
- Worth noting that the "NU20" contains only 1/7 amount of U-235 with respect to the ANSI standard.

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Next Steps

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Object to be detected	"NU10", "NU20"	"NU10", "NU20"	1 kg HEU or equiv.

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Object to be detected	"NU10"	"NU20"	5 kg LEU
U-235 amount	71 g	142 g	975 g
Inspection time	90±4sec	90±3sec	90 sec
PD at 68% confidence level	>74.2 %	>97.8 %	>90 %
PFA at 68% confidence level	< 3.8 %	< 3.6 %	< 5 %
Condition Cargo loading	Empty		Empty, filled with paper, Al or steel
Simulant location	A specified location		Full cargo volume

IEEE ANSI N42.41-2007, Category A

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Concluding Summary

- Experimental tendencies, eg. distance square dependence, were found reasonable.
- NU20 / NU10 ratio not being two may likely due to self-shielding. Simulations under way could confirm this.
- The evaluated U-235 detection capability (PD and PFA) is very encouraging, compared with the ANSI standard N42.41-2007 for small article (Category A).

Next step

- The experimental active BG was larger than expected. Threshold energy calibration of tens CTMFDs will reduce active BG.
- Use of moderator will enhance fission rate and reduce active BG.
- Similar tests are planed with variation in simulant location in cargo, and then cargo loading (newsprint, Al, or steel) in this fiscal year.
- We are waiting for approval of DD source operation at the nominal source intensity for demonstrating the PD and PFA.

Future work

- Other arrangement like single-sided stand-off detection, and/or larger system for scanning larger container categories.