16th ANS Topical Meeting on the Technology of Fusion Energy

O-I- 6.4

Research and Development of Landmine Detection System by a Compact Fusion Neutron Source

September 14, 2004

Monona Terrace Community and Convention Center

Madison, WI

IAE, Kyoto University

Kiyoshi Yoshikawa

PROGRAMME COMPONENTS

Mine and UXO Clearance

Anti-Personnel = 258,735

Anti-Tank = 12,185

UXO = 2,172,037

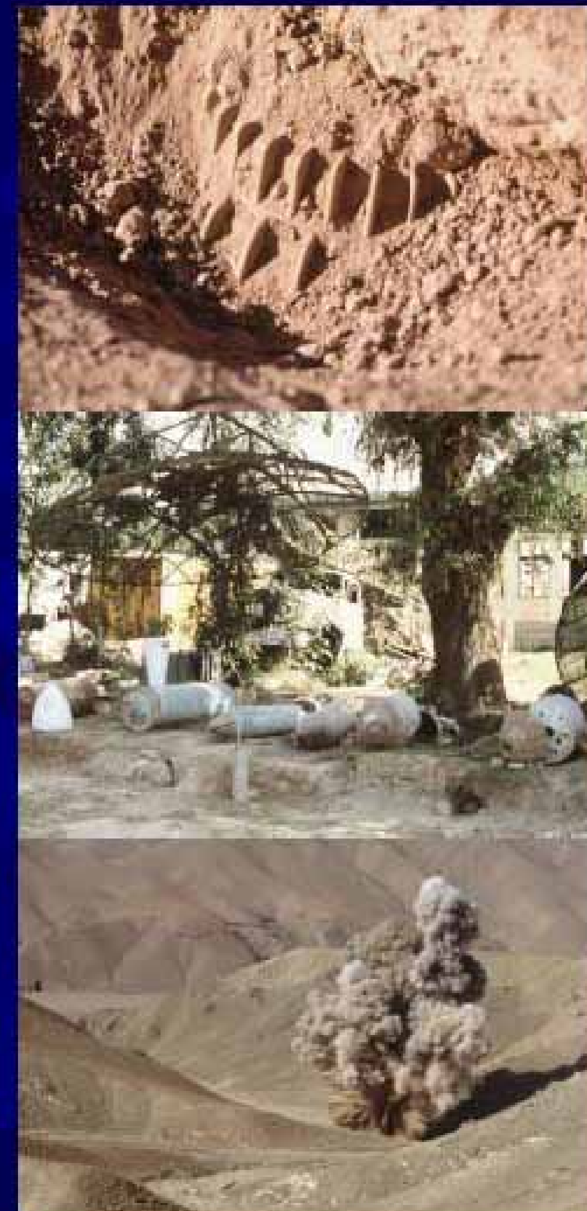
Total devices destroyed = 2,442,957

Mined area cleared = 254 sq km

Battle Area cleared: 450 sqkm

MRE Trained : 9,700,000

10/12/2002



Impact - Current Victims

No National Survey

- 150 – 300 Victims/Month

- 50 % UXO's

10/12/2002

HISTORY

- Mechanical clearance began soon after WW 1
- Flails and Rollers were soon tested

Early mine plow ?

EARLY FLAIL

Early mine detection

Characteristics of the landmines found in Croatia

Mine	Type	Buried -B, Surface -S	Metal Content	Dimensions	Weight total	Weight explo.	Kill/ Casualty radius
				mm	kg	kg	m
PMR_2A	AP	S	m	ϕ66×122	1.70	0.10	1/25
TMA_3	AT	B	n	ϕ260×80	6.50	6.50	
PMA_2	AP	B	n	ϕ60×33	0.135	0.10	1/25
PMA_3	AP	B	n	ϕ104×40	0.183	0.035	1/25
TMR_P6	AT	B, tilt rod on S	m	ϕ290×137	7.20	5.10	
TMM_1	AT	B	m	ϕ250×85	8.65	5.60	
PROM_1	AP	B,protruding assembly on S	m	ϕ75×329	3.00	0.425	50/100
TMA_4	AT	B	n	ϕ280×65	6.30	5.50	
TMA_5	AT	B	n	300×275×113	6.60	5.50	
PMA_1	AP	B	n	142×68×35	0.40	0.20	1/25
MRUD	AP	S	m	231×46×89	1.50	0.90	50/200
TMA_1	AT	B	n	ϕ310×100	6.50	5.40	
TMA_2	AT	B	n	330×260×100	6.50	5.40	
PMR_3	AP	S	m	ϕ80×150	1.70	0.41	20/100

Requirements for Landmine Detection

>30g in depth of 20cm,100% detection

IAEA INITIATIVES

1) IAEA Report,"Application of Nuclear Techniques to Anti-personnel Landmines Identification", Report of the First Research Co-ordination Meeting, Zagreb, Croatia, IAEA/PS/RC-799, Nov. 23-26, 1999.

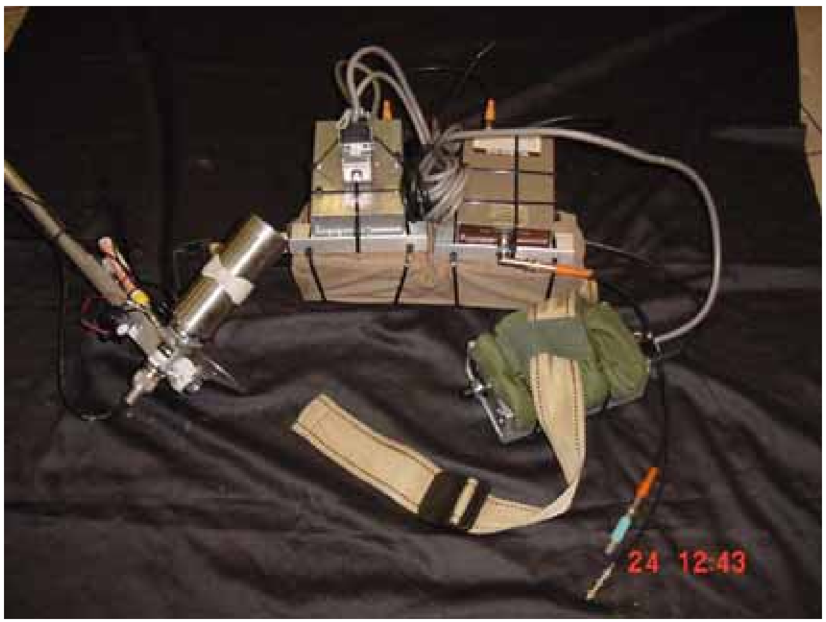
2) IAEA Report, "The Application of Nuclear Methods to Anti-personnel Landmines Identification", Report of the Second Research Co-ordination Meeting, Saint Petersburg, Russia, IAEA/PS/RC-799-2, Sept.11-14, 2001.

3) IAEA,"Application of Nuclear Techniques to Anti-personnel Landmines Identification", Third Research Co-ordination Meeting, Wien, Austria, IAEA HQ, May 19-23, 2003.

Nuclear methods under development

Name	Principle	Advantages	Issues	Status	CRP Groups
Methods to find buried objects					
X-ray Backscatter	X-rays backscattered form soil can be imaged using collimated detectors	Real time images sufficiently detailed to identify landmine size and type, independent of surface clutter.	Limited x-ray penetration depth into soil, speed of ground coverage, portability, cost (minimum $250K).	Tested with plastic and metal antitank mines as well as anti-personnel mines.	Shope (USA)
Neutron Backscatter	Quantity of neutrons backscattered from soil can indicate concentrations of hydrogen.	Focuses on plastic landmines, insensitive to metallic clutter, emulates a metal detector (simple to use), simple and low cost, portability (<$10K)	Sensitivity to hydrogen clutter, possible depth limitation, dependence of soil moisture stand off distance dependence.	Successful in laboratory	Brooks (SAF) Bom (HOL)
Positron annihilation Compton scatter imaging (PACSI)	Gamma rays backscattered from soil can indicate density of buried objects.	Simple and low cost method for forming 3D images to a depth of 20-30 cm. Potentially low cost (about 10 k$)	Experimental test needed.	Demonstrated in computer simulation.	Tickner (AUL)
Methods to identify composition of buried objects					
Neutron-induced gamma rays	Neutrons enter the soil and cause emission of gamma rays. Identify elemental compositions from the gamma ray energies.	Identify composition of buried objects to determine presence of explosives. Compact portable system. Easy operated training.	Speed limited by neutron source strength. Background gamma rays must be subtracted.	The PELAN method (Prof. Vourvopoulos) has been demonstrated successfully with unexploded ordnance and is ready for field testing in minefield.	Vourovoupolous (USA) Hussein (CAN) Valkovic (CRO) Viesti (ITA) Ringbom (SWE)
Backscattered neutrons	Measure the energies of backscattered neutrons.	Good penetration of neutrons into soil. High neutron cross sections.	Neutron energy measurement requires complex electronics & analysis.	Tested in laboratory. and verified by simulations	Csikai (HUN) Hlavac (SLV) Kuznetsof (RUS) Hussein (CAN)

The battery-powered, hand-held HYDAD-H landmine detector. (Univ. of Cape Town).



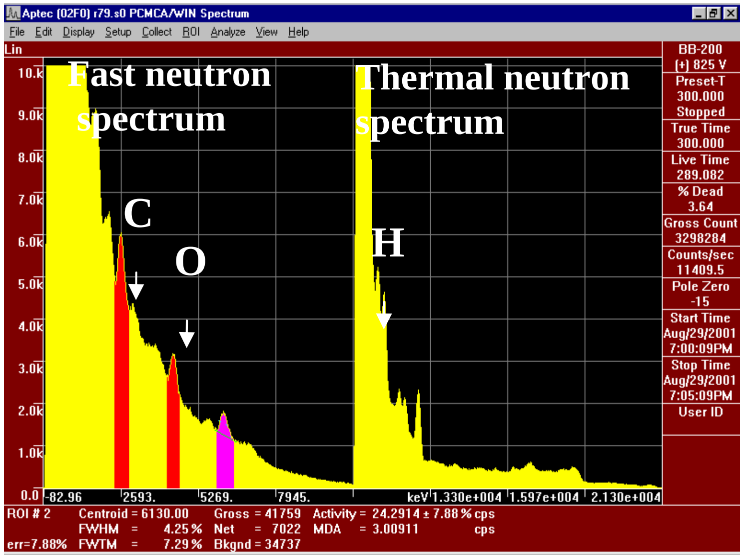
^{3}He proportional N counter with ^{252}Cf source.

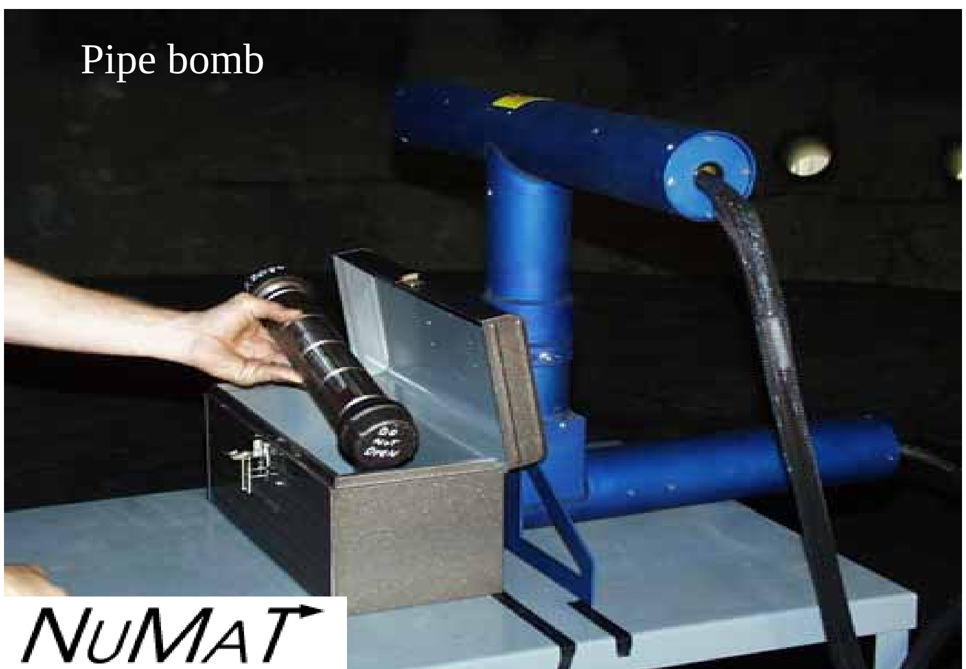
Associated Particle Detection

Khlopin Institute St:Petersburg

Prototype of the mobile device with 2 μg ^{252}Cf source with various investigated objects: TNT imitators, metallic cylinder, wet root etc.

PELAN TRIALS, 8/99, OHIO, Battle





Outline of Project

Sensing technique

In 5 years, develop techniques to be able to identify

Landmine exists?

Plastic or LM? Then what kind ?

Then, where is it?

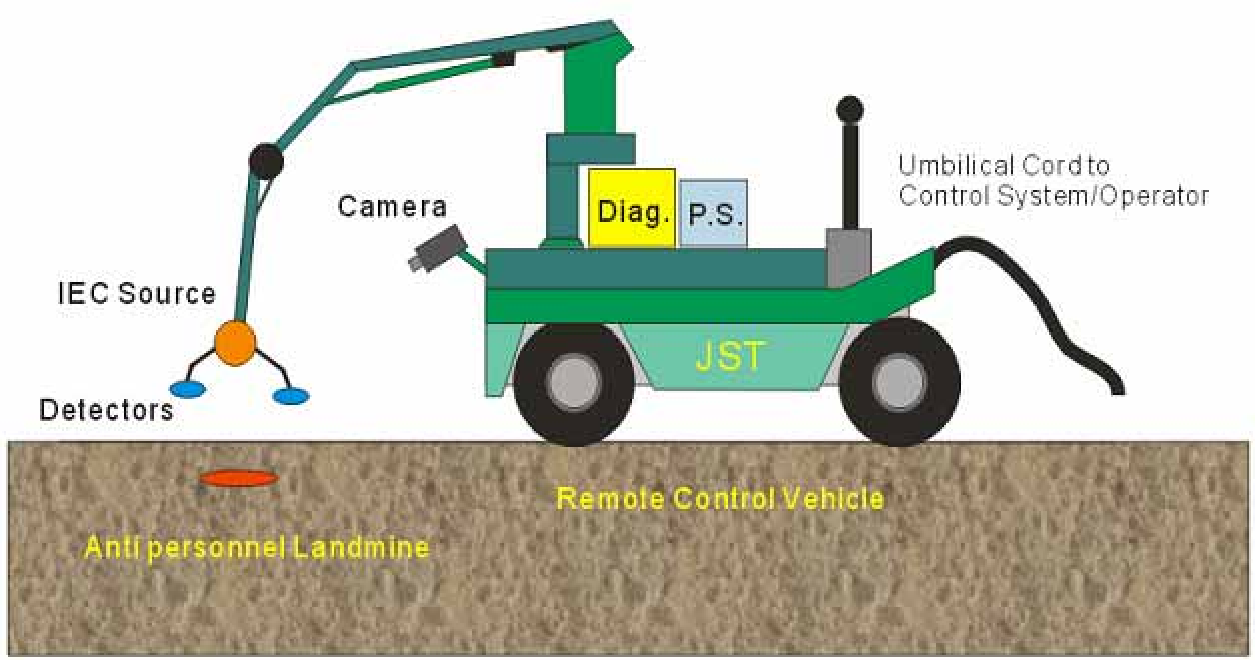
Detection thru neutron-related reactions, able to identify

Constituents ; (n, γ),(n,n' γ)

Location; tomography, and by

Innovative IEC neutron source;

>10^8n/s, in Pulse, CW modes



R&D Organization & Budget

supported by **JST**

(Japan Science and Technology Corporation Agency)

1)R&D of compact IEC

CW/pulse IEC

Kyoto-U, Kansai-U.

CW/Pulse power supply

TIT

2) R&D of LM Detection

Diagnostics

Kyoto-U., TIT, Kyushuu-U.

Tomography

Kyoto-U., JAERI,Wakasa-bay Energy Res. Center,

Total system

Kyoto-U., Nikki Co.

Budget(2002.9-2006.3); approx. US$2~2.5M

Detection Method of Landmine -1-

Atomic number ratio in the explosive has a unique value

Kind of Explosives	Atomic Number Ratio			
	H	C	N	O
TNT	3	7	3	6
Pentrite	8	5	4	12
Hexogen	2	1	2	2
Ammonium Nitrite	4	-	2	3

- **Measurement of Capture γ-rays**

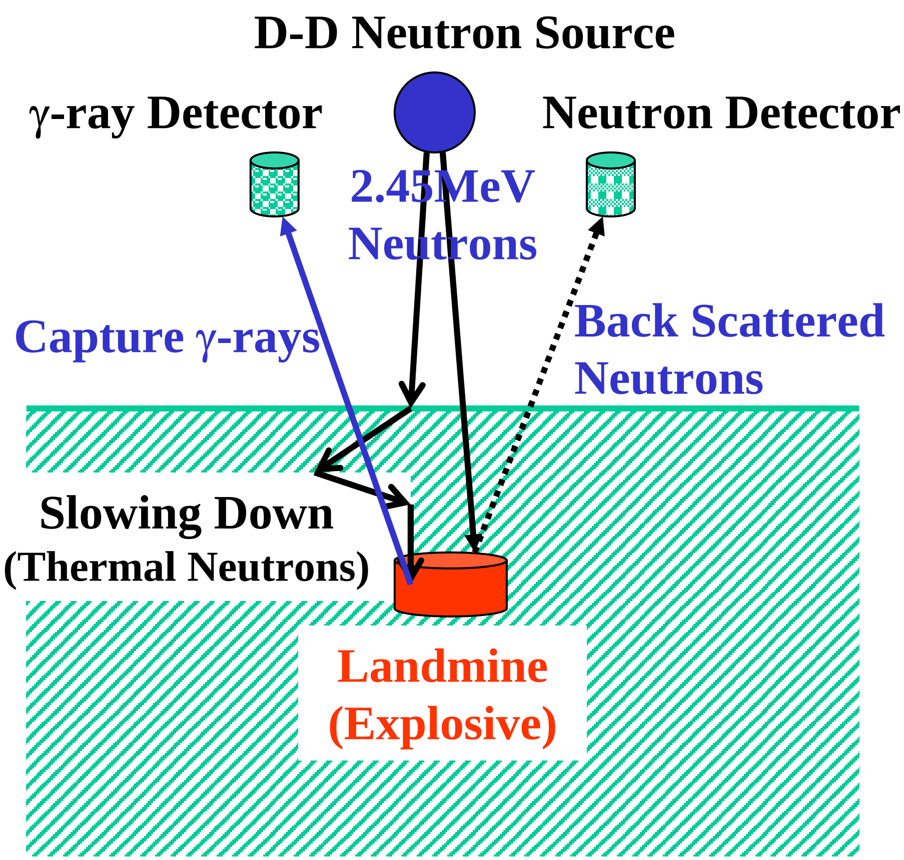
  H(n, γ) reaction --- 2.22MeV γ-ray emission

  N(n, γ) reaction --- 10.83MeV γ-ray emission

- **Measurement of Back Scattering Neutrons**

  H(n, n) reaction --- Scattering cross section of H is large

Detection Method of Landmine -2-



Neutron Detector

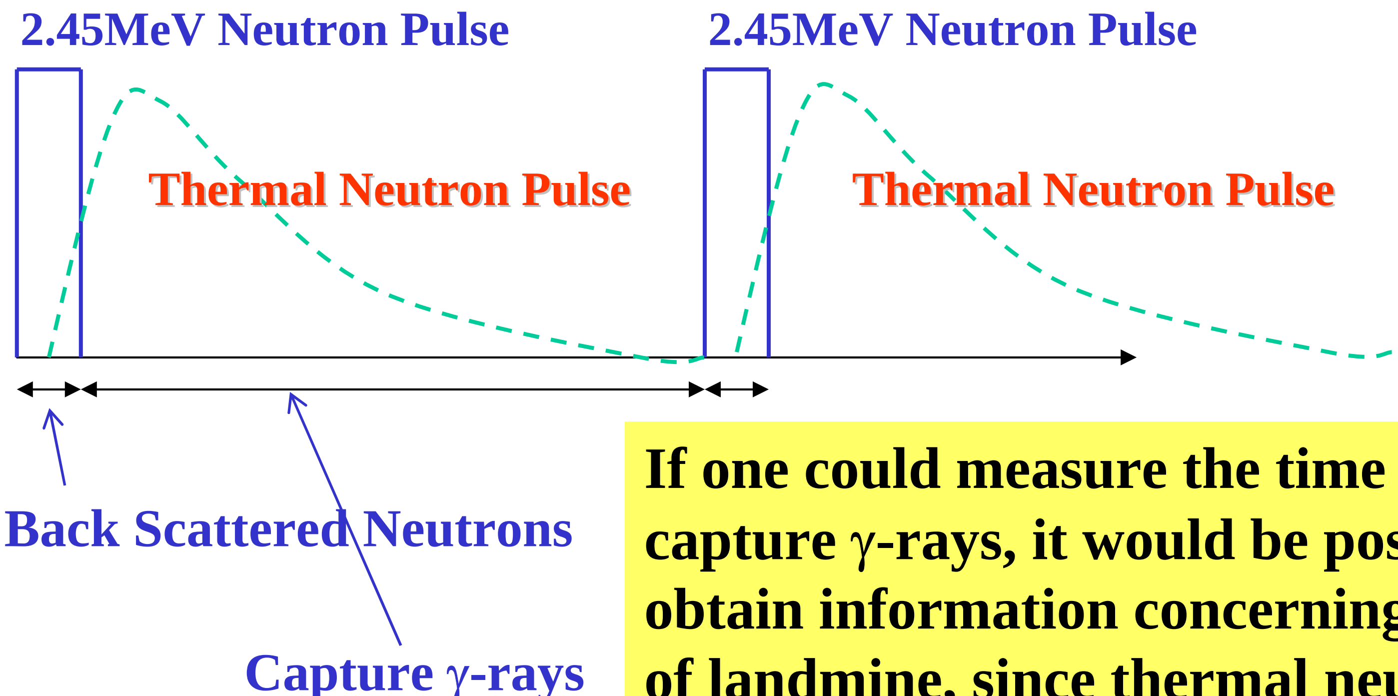
- **^{3}He Proportional Counter**
- **Organic Scintillator (γ-rays are detectable)**

γ-ray Detector

- **NaI Scintillator**
- **CsI Scintillator**
- **BGO Scintillator**

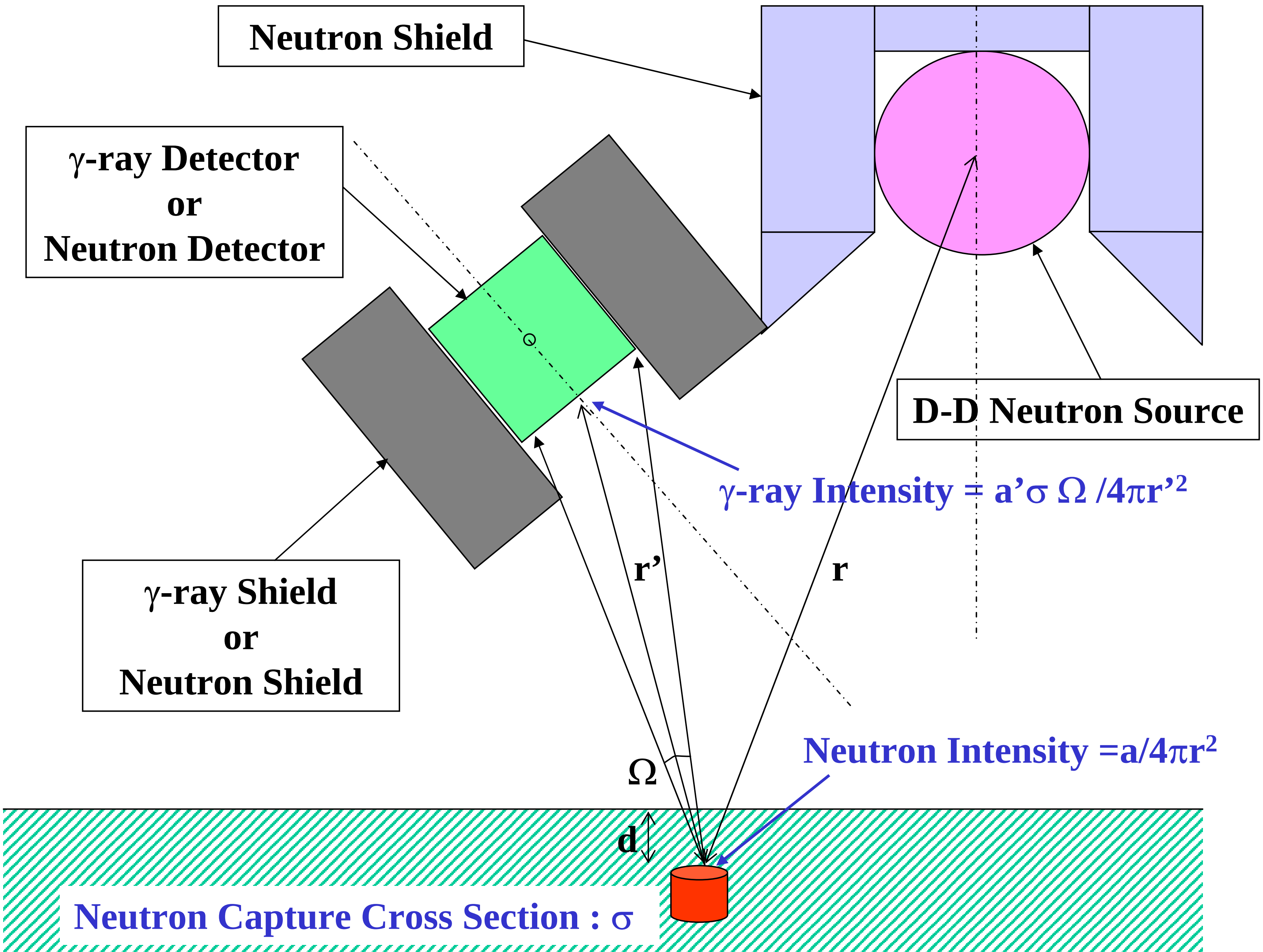
Tomography technique is applicable by using plural detectors

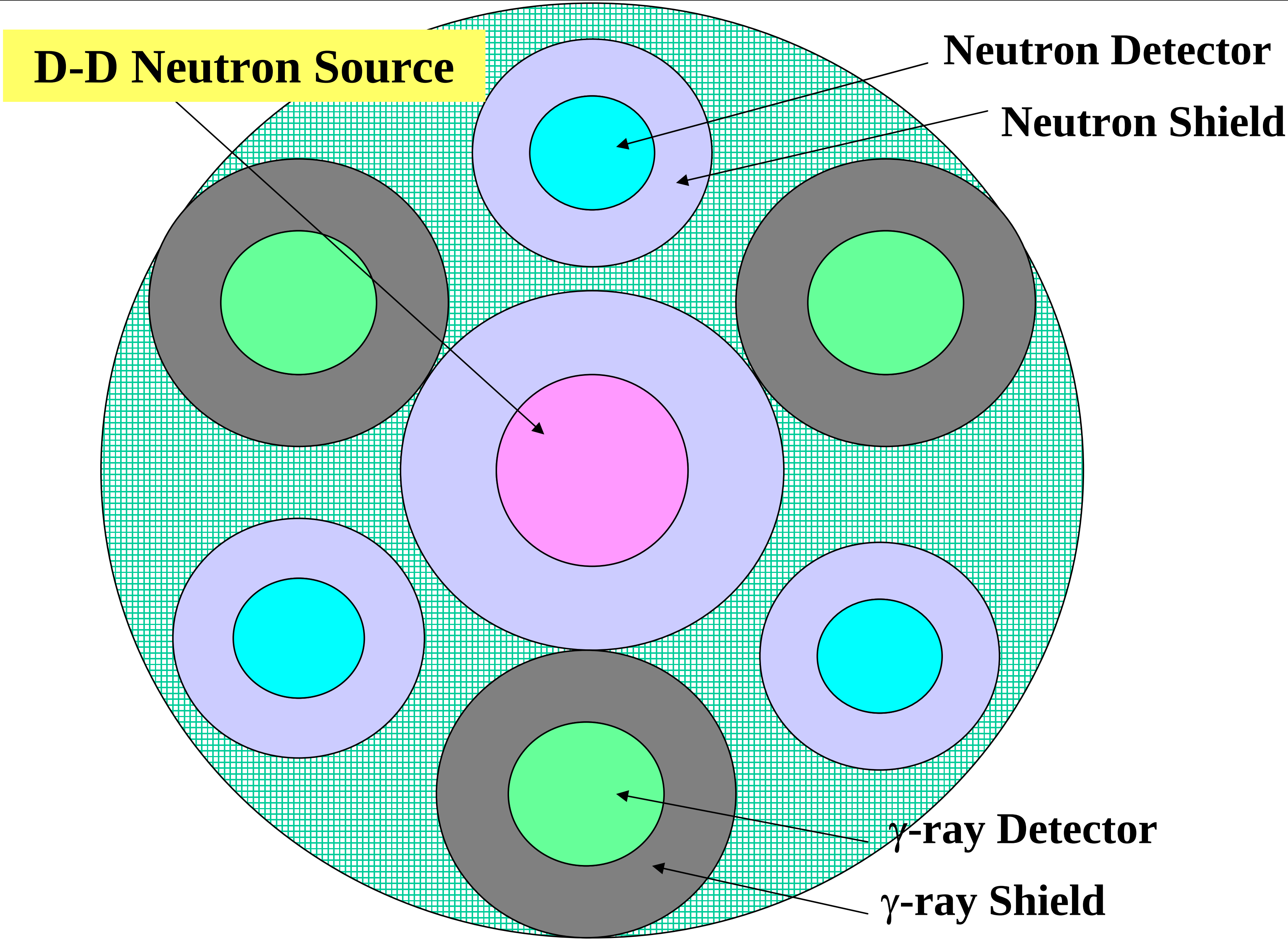
Detection Method of Landmine -3-



If one could measure the time behavior of capture γ-rays, it would be possible to obtain information concerning buried depth of landmine, since thermal neutrons reach their peak at a certain time after the injection of neutron pulse depending on the depth from ground surface.

If one could measure the time behavior and time-dependent spectrum of back scattered neutrons, it would be possible to obtain information concerning buried depth of landmine.


Neutron Shield
γ-ray Detector
or
Neutron Detector
D-D Neutron Source
γ-ray Intensity = a'σ Ω /4πr'²
r'
r
γ-ray Shield
or
Neutron Shield
Neutron Intensity =a/4πr²
Ω
d
Neutron Capture Cross Section : σ



Example of array of neutron source and detectors

Compact Power Supply Mountable on Vehicle

Components and specifications: DC and Pulse operation

Compact Generator (16kW) — **Control (UPS: 2kW)**

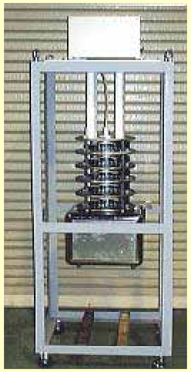
- **HV DC (CVCC 100kV, 120mA, 12kW)**
  - **Pulse (100kV, 10A, 50μs, >200pps)**
- **Measurement system (2kW)**

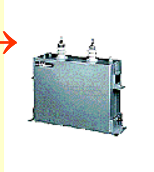
Present status

Switch used in oil →

Condenser →

H.V. DC Power Supply ↓





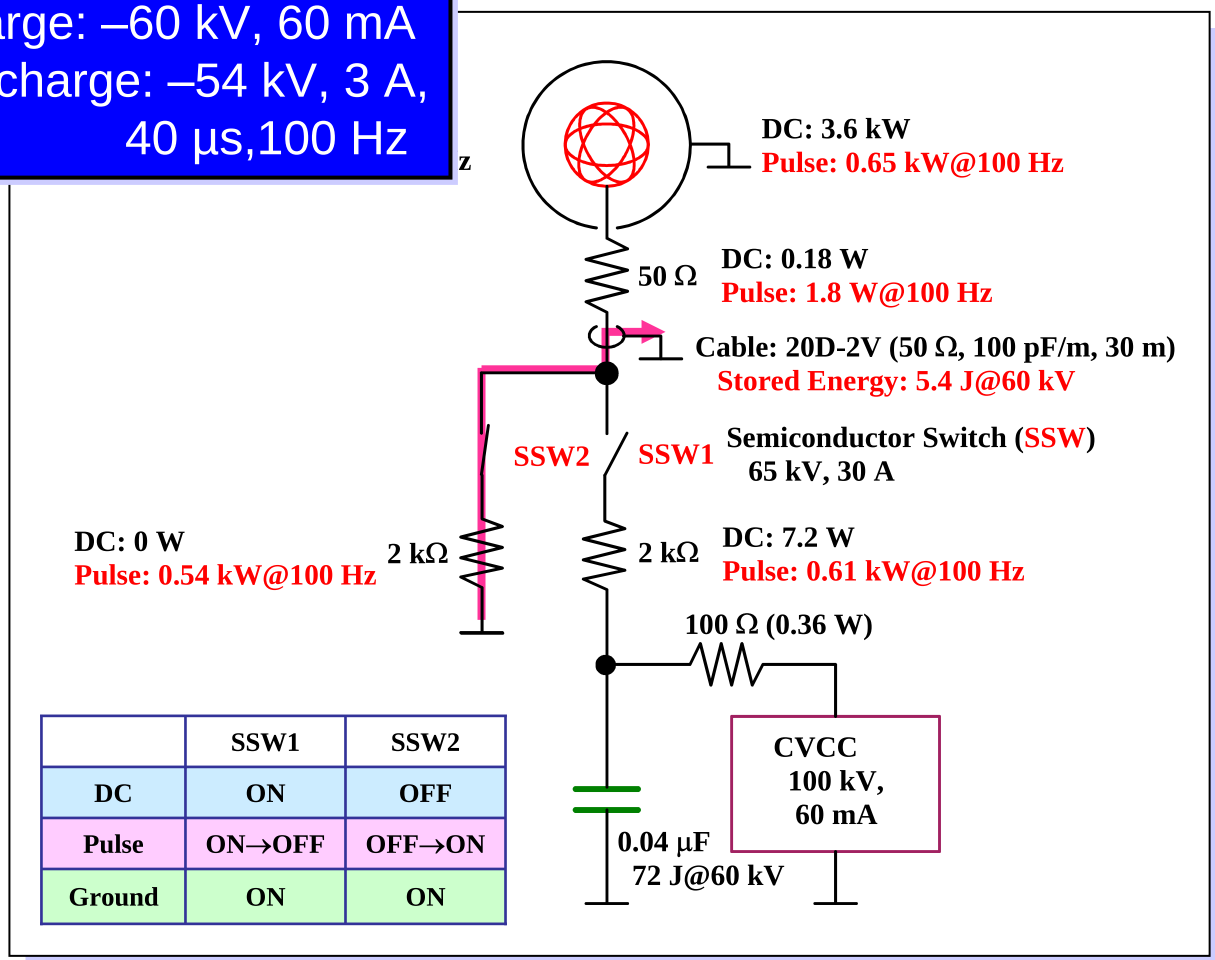
Issues of development

- **Compactness**
- **Robustness**
  - **Modular type**
  - **Molded**
- **Fail safe system**
- **High Voltage Connection**
  - **Dry type connection**

Image↑

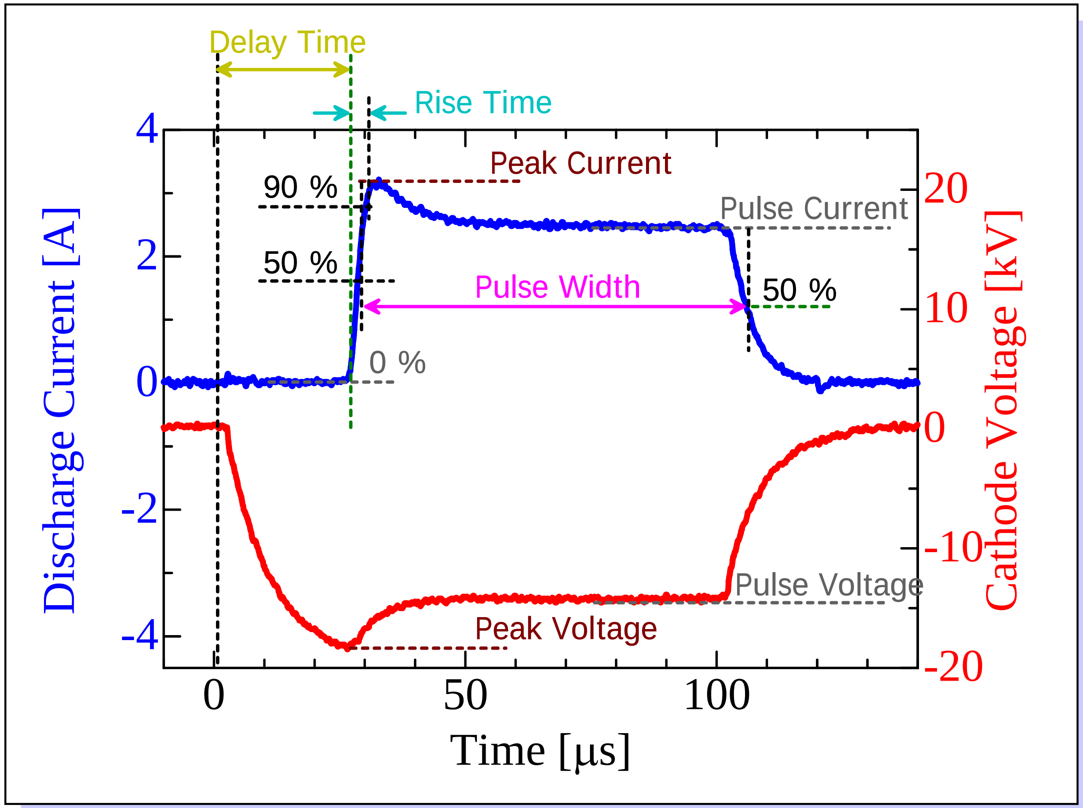
Circuit of Prototype Pulse Generator System

CW Discharge: –60 kV, 60 mA
Pulsed Discharge: –54 kV, 3 A, 40 μs,100 Hz



	SSW1	SSW2
DC	ON	OFF
Pulse	ON→OFF	OFF→ON
Ground	ON	ON

Typical Waveforms (Long Pulse)

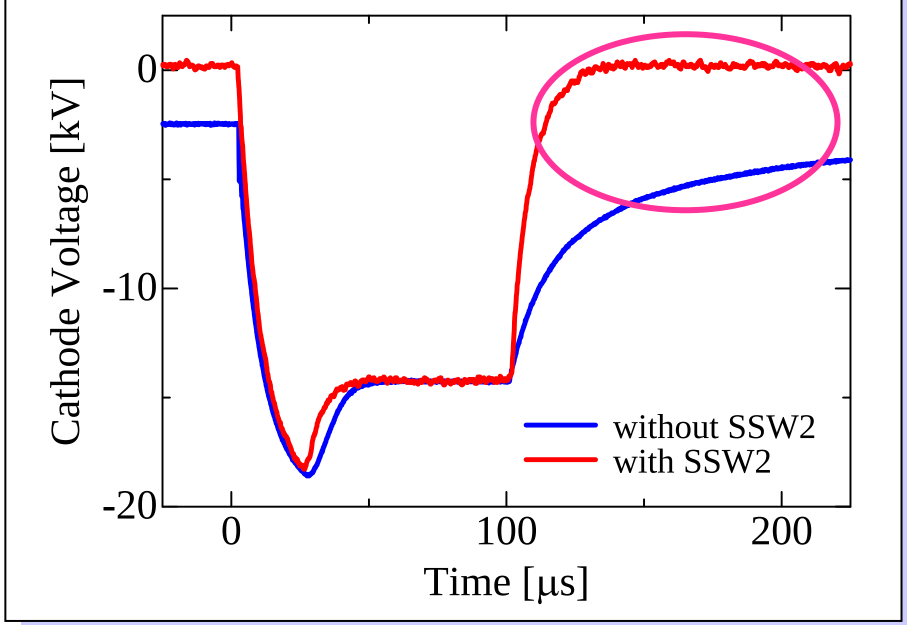


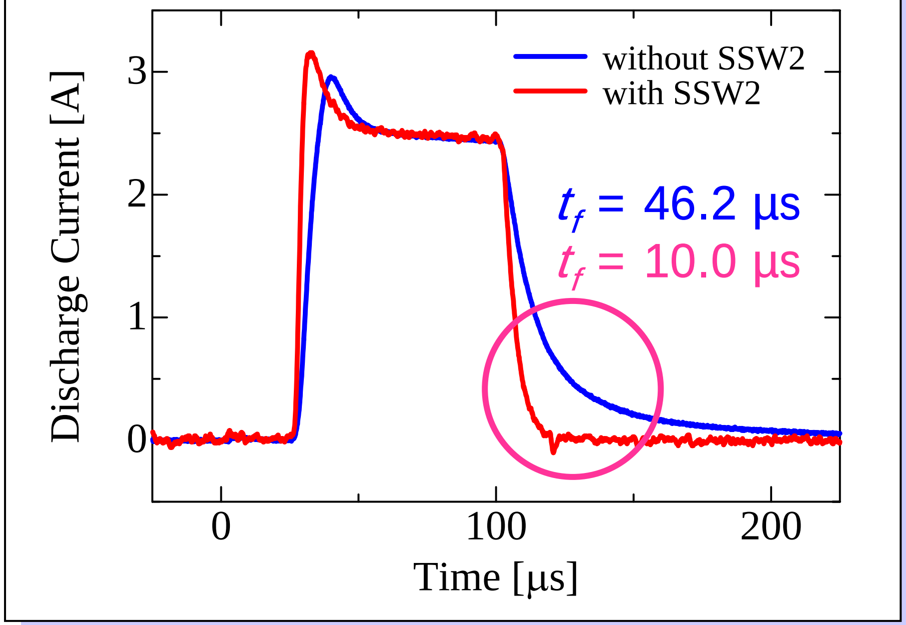
Pressure: 14.0 mTorr/H_2
Charging Voltage: -20.0 kV
Storage Capacitor:1.1 μF

The delay will be reduced by assistance of magnetron discharge developed at Kyoto Univ.

Effect of SSW2

Pressure: 14.0 mTorr/H_2, Charging Voltage: -20.0 kV, Storage Capacitor: 1.1 μF

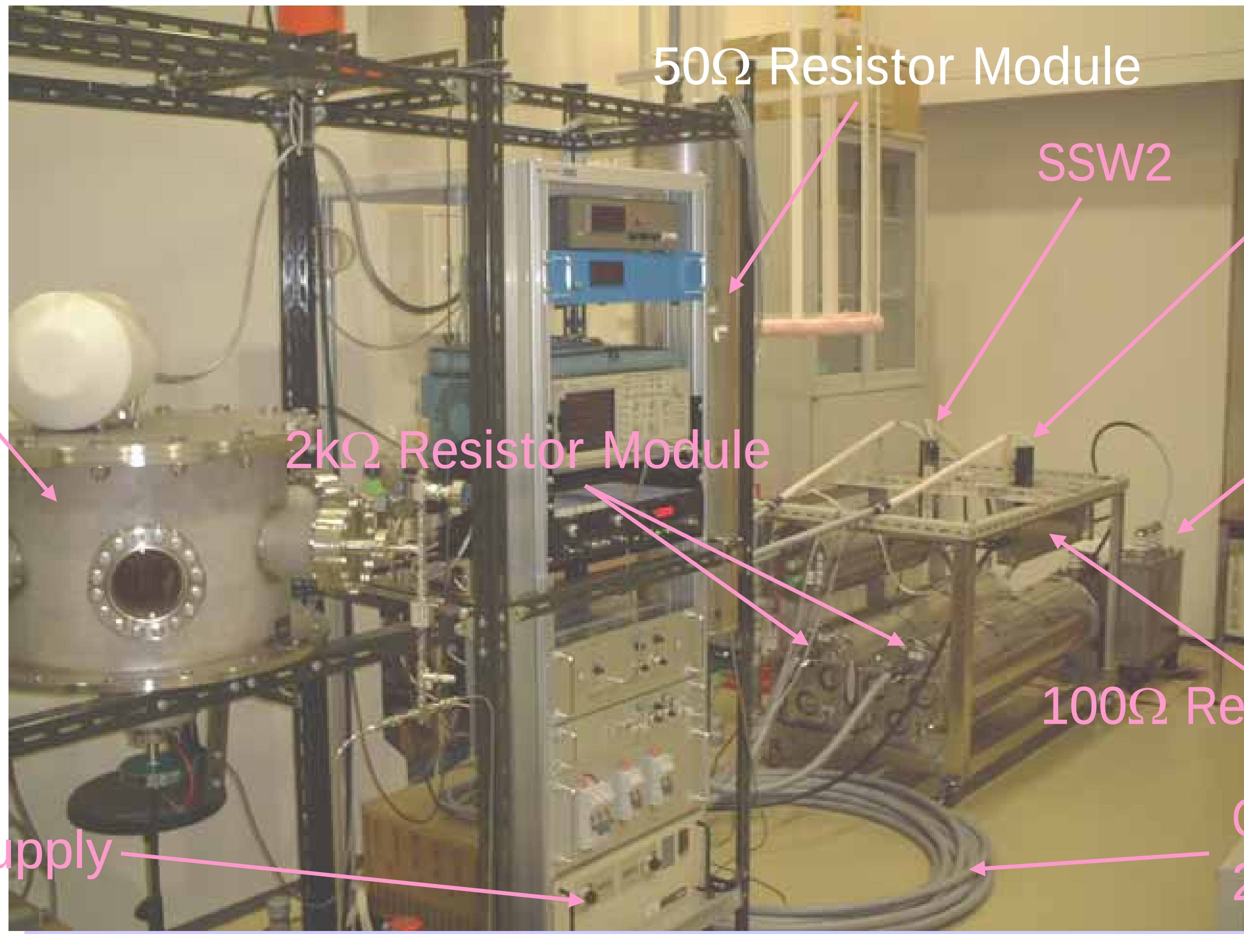




Suppression of the neutron generation caused by the afterglow of discharge pulse

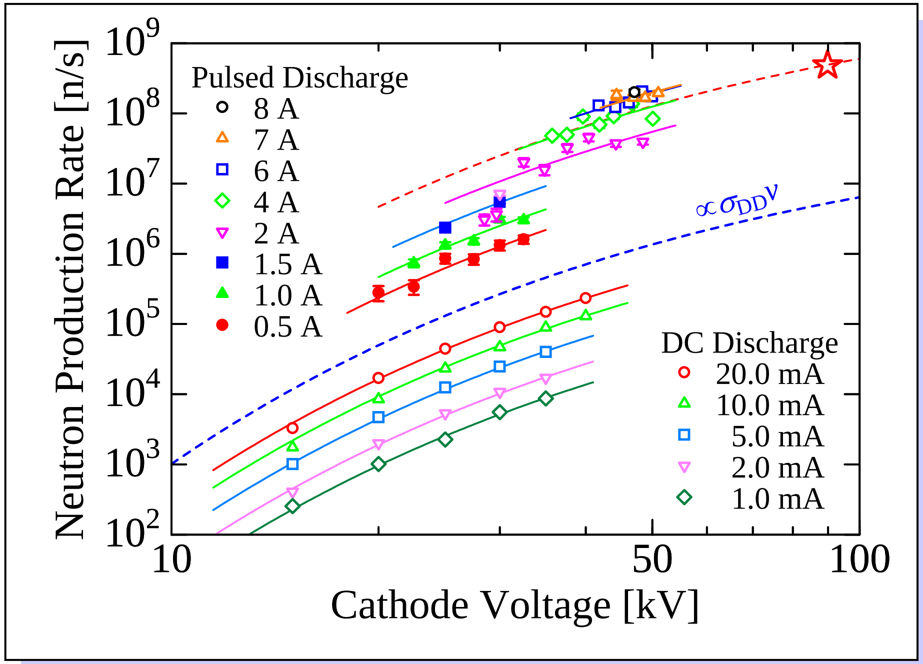
Higher S/N ratio for landmine detection

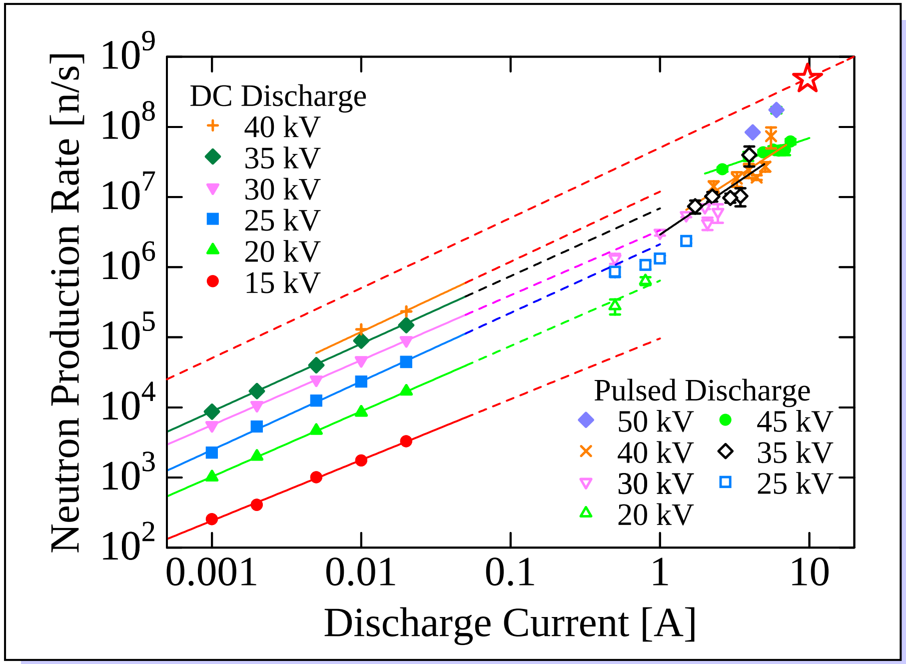
Experimental Setup



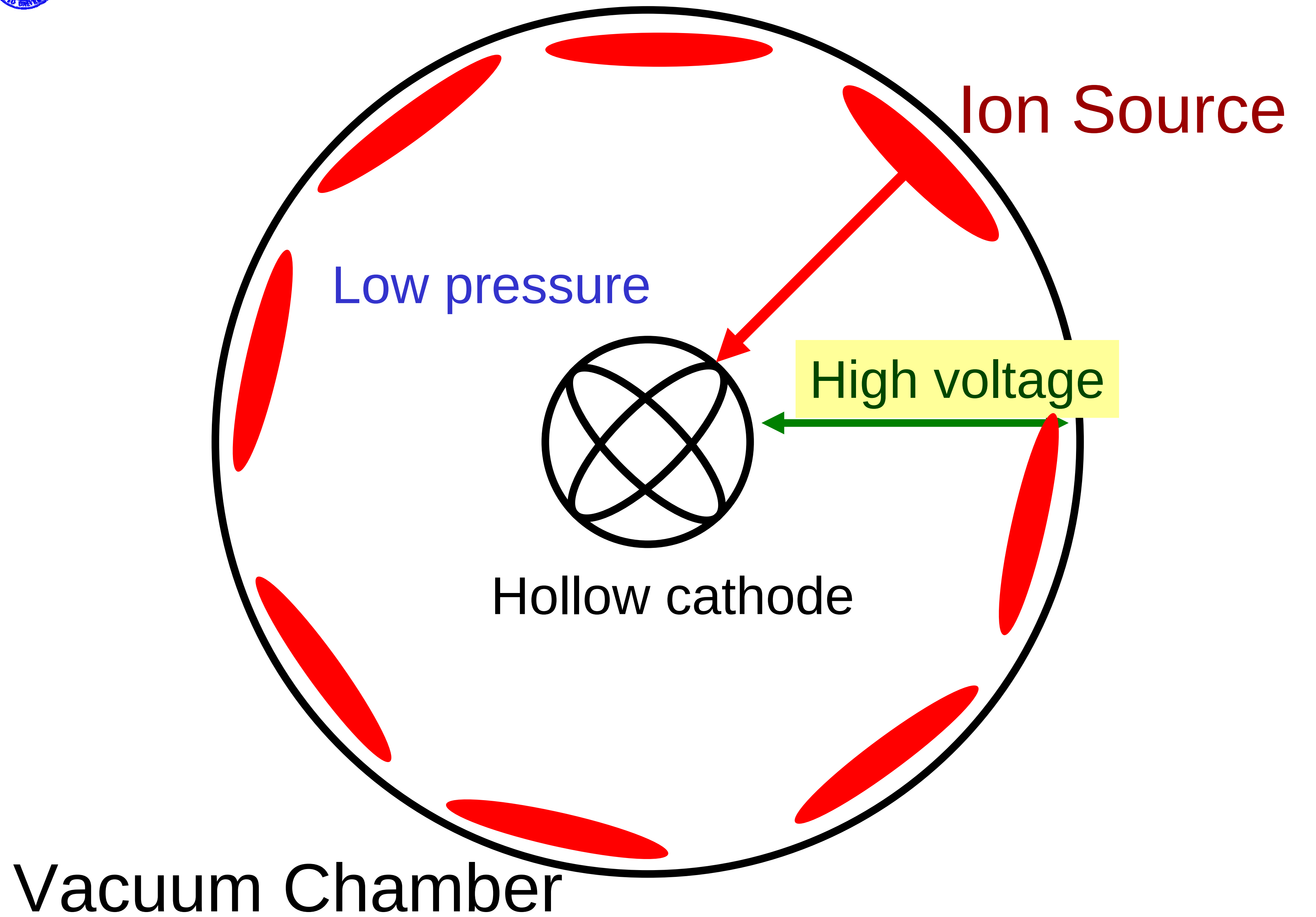
Neutron Production Rate

Final Target (–90 kV, 10 A)

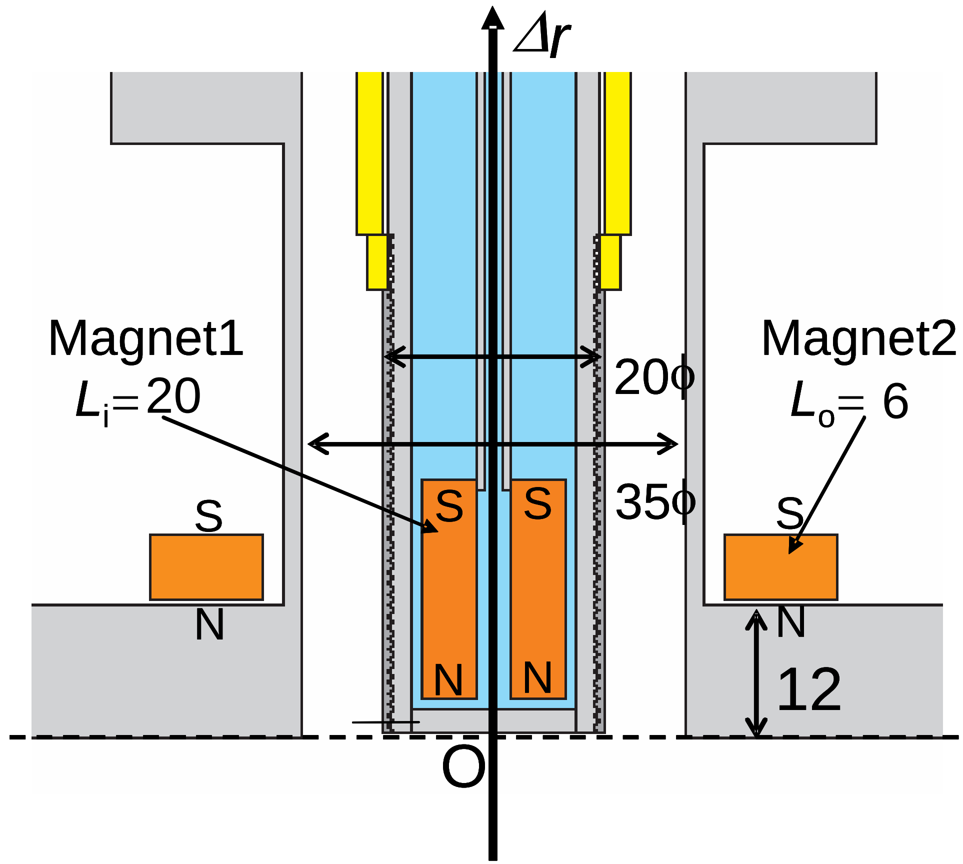




The maximum neutron production rate
2.0×10^8 n/s for –51 kV, 7.3 A
obtained in a pulsed discharge

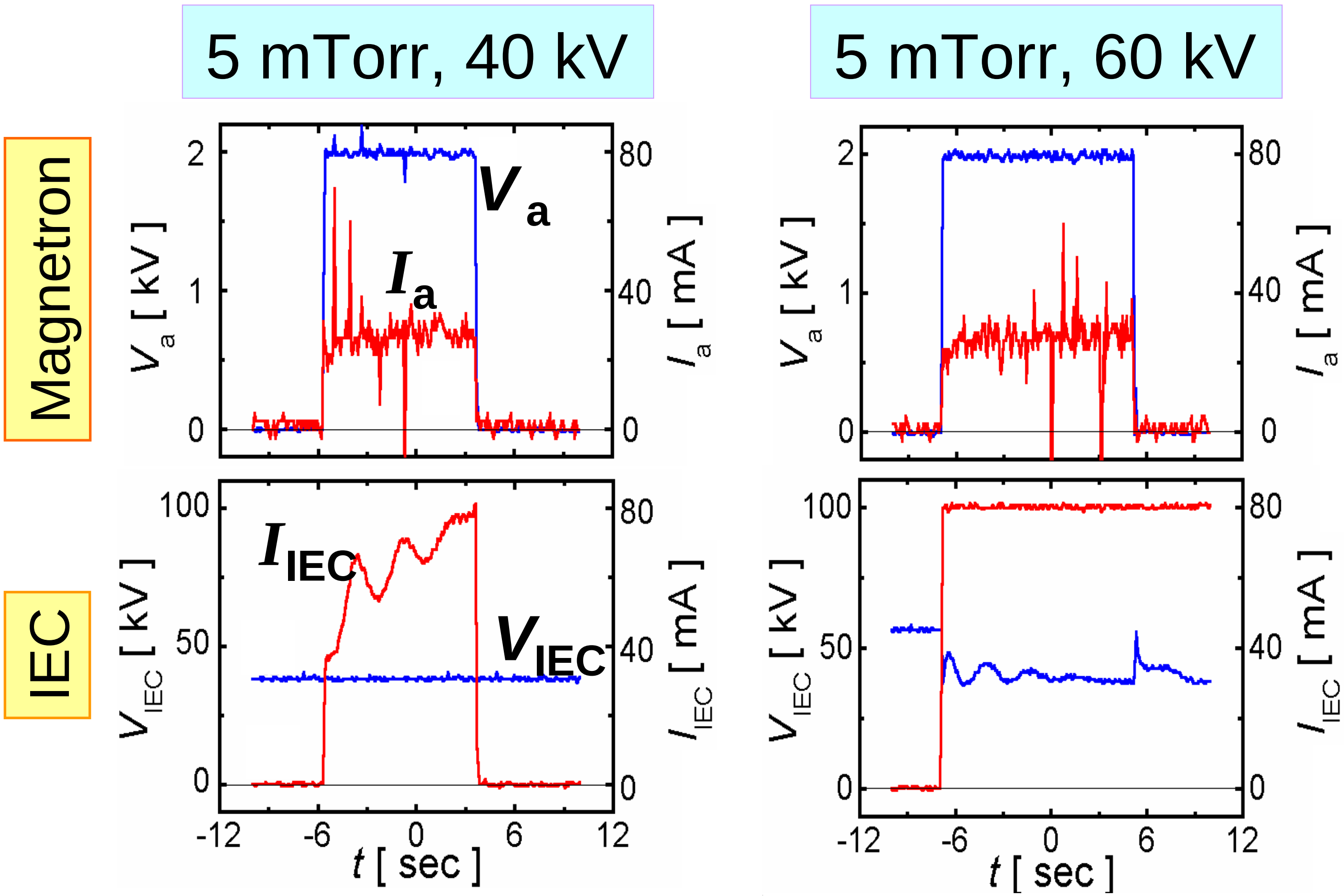

Ion Source
Low pressure
High voltage
Hollow cathode
Vacuum Chamber

Magnetron-type Ion Source at Negative Potential



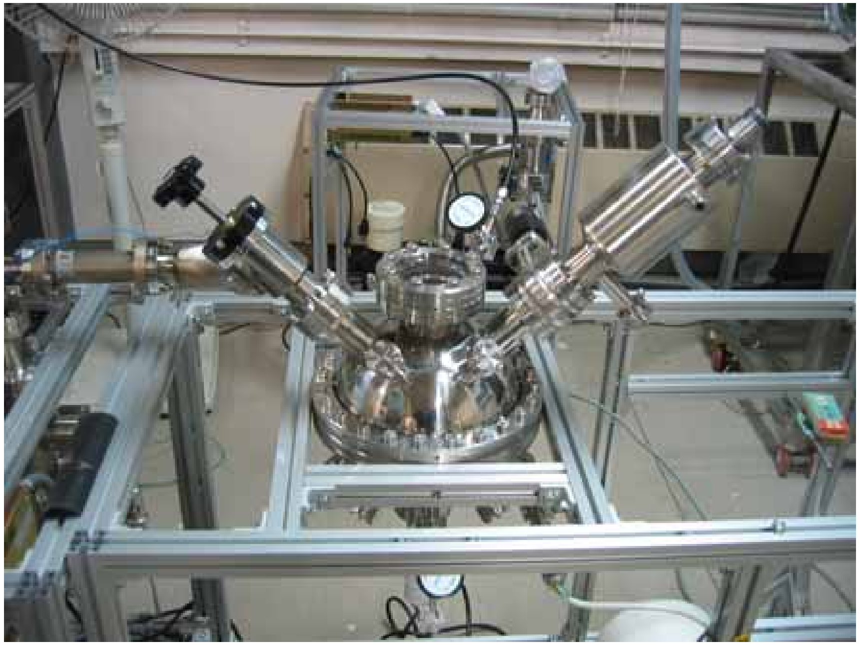
Controllability of Pulse Operation Magnetron Discharge

IEC Pulse Operation

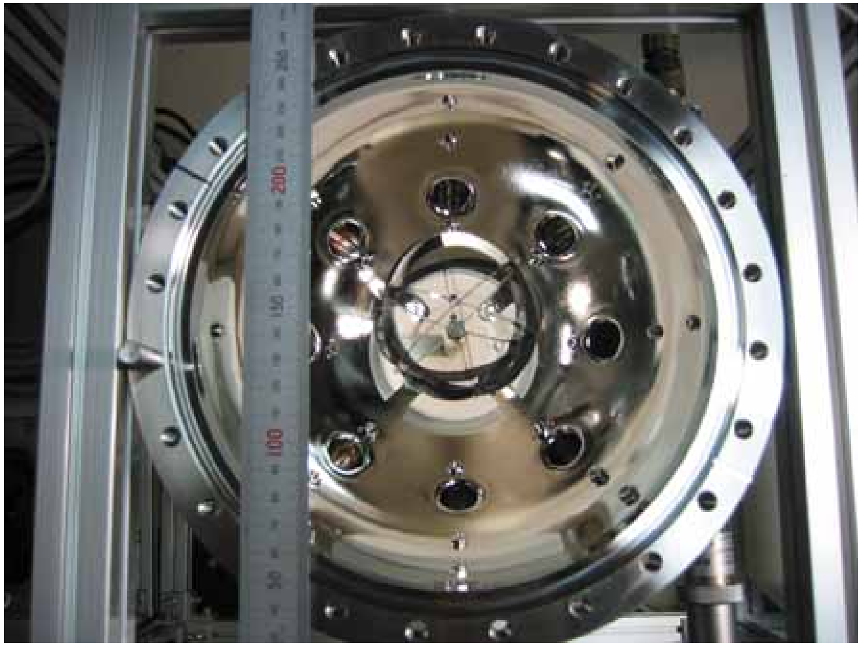


Design & Fabrication of an Ultra-small Neutron Source

- 1×10^{-6} Pa achieved after baking
- a 65ϕ O.D cathode supported by upper feedthrough
- 9CF34 flanges for ion production by magnetron discharge



200ϕ vacuum chamber



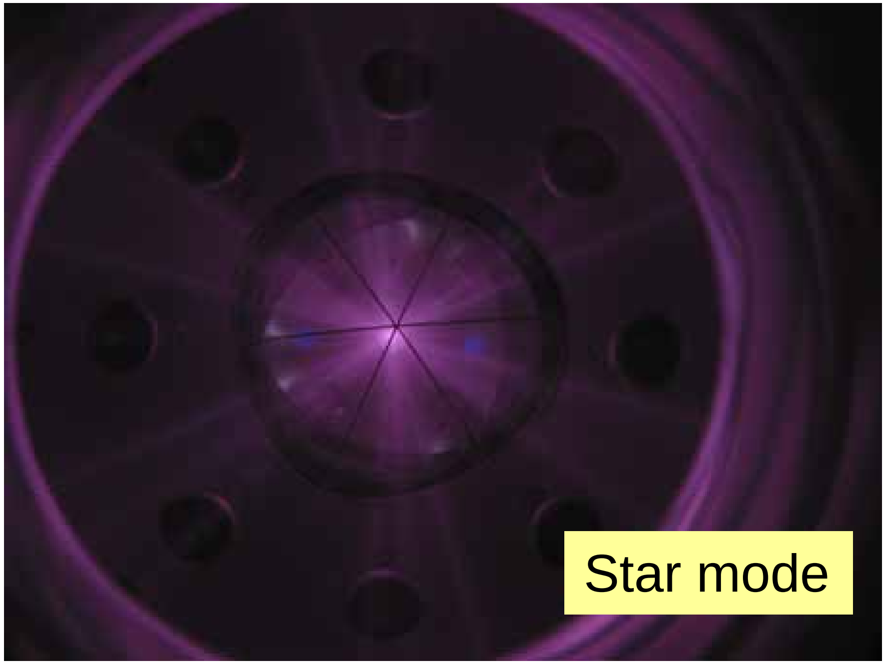
Hollow cathode and its support

Ultra-compact & high-voltage standing capability

100kV feedthrough

Preliminary testing

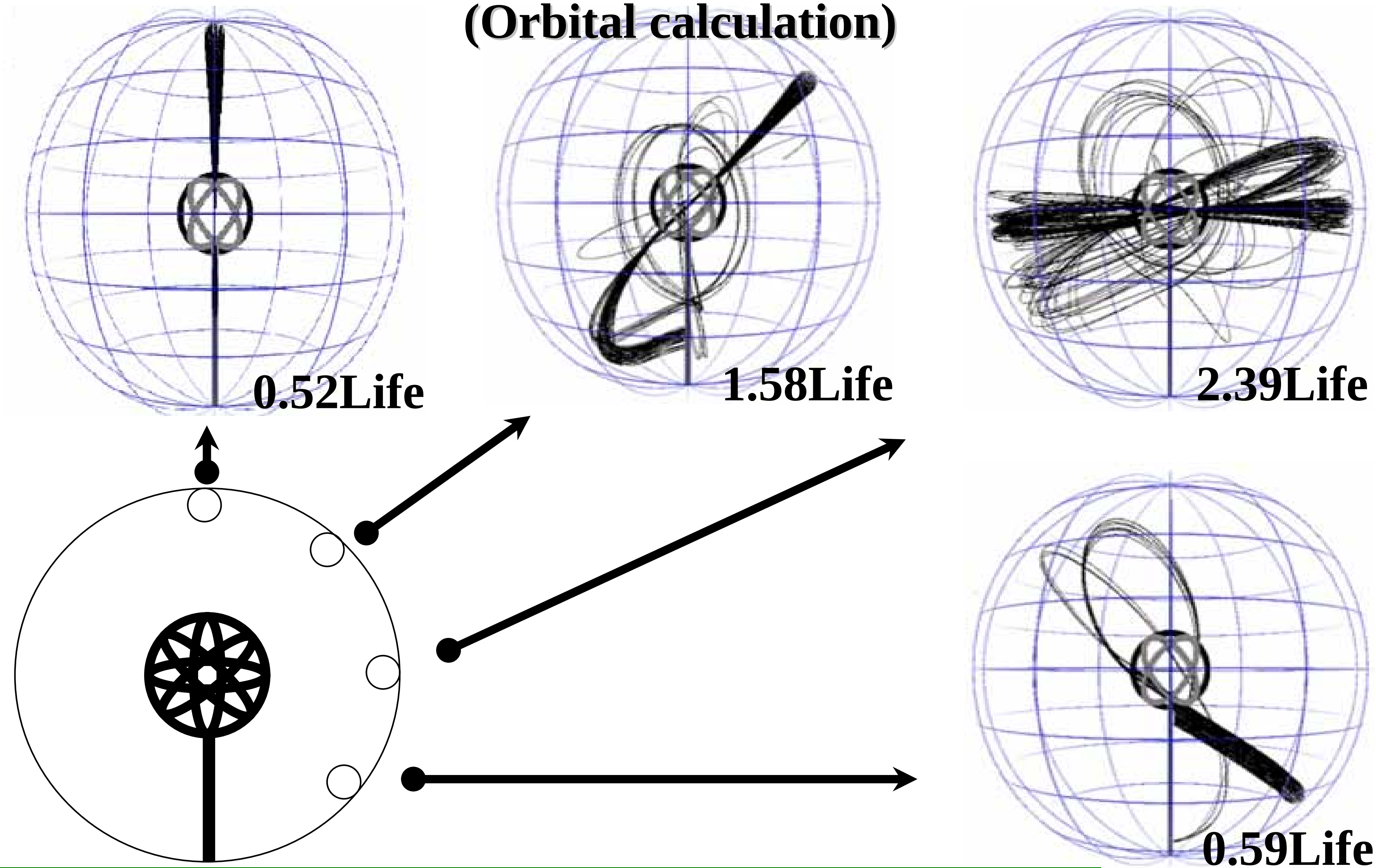
- **CF70 flange feedthrough for 100kV**
- **80kV applied for 10^{-5} Pa**
- **neutron production for 30 ~ 40kV**



IECFdischarge(30kV, 6mA, 2.25Pa)

Trajectories of Various Positions of Ion Source

(Orbital calculation)



The ion source setting on the horizontal plane is very efficient.

Ion Bombardment

Numerical simulation

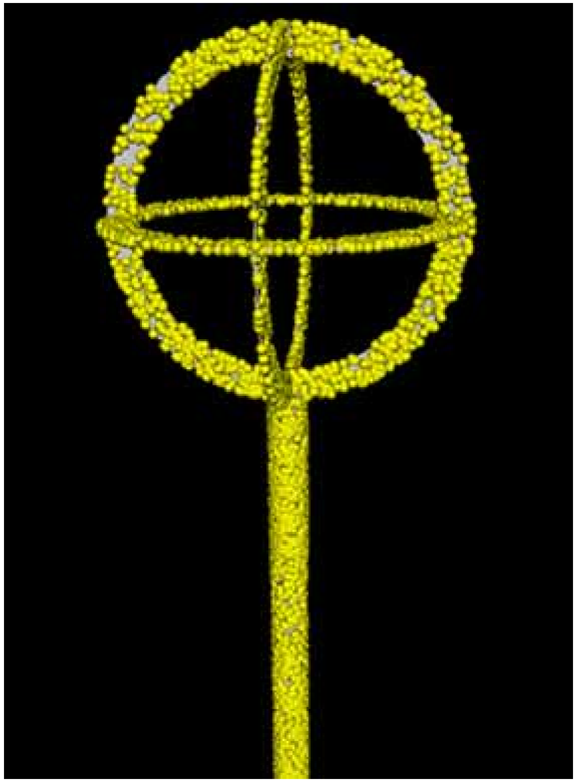


Photo of the experiment

About 50% ions are lost by hitting the feed-through

In the IEC simulation, we can not neglect the existence of the feed-through and the cathode structure.

Star Mode Discharge (1Pa, 10kV)

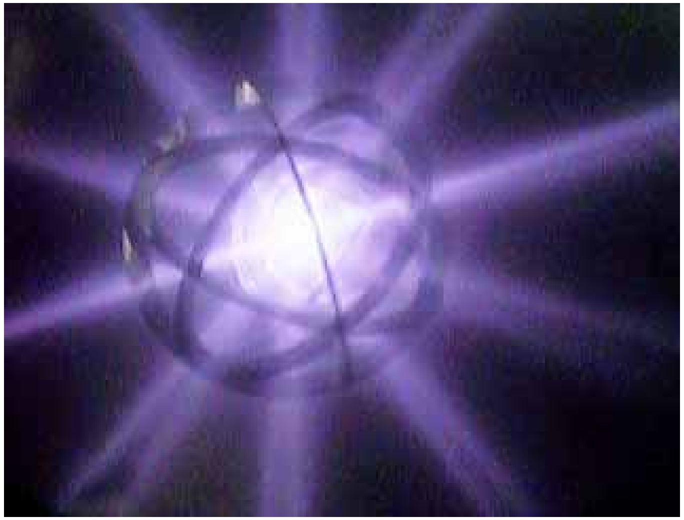
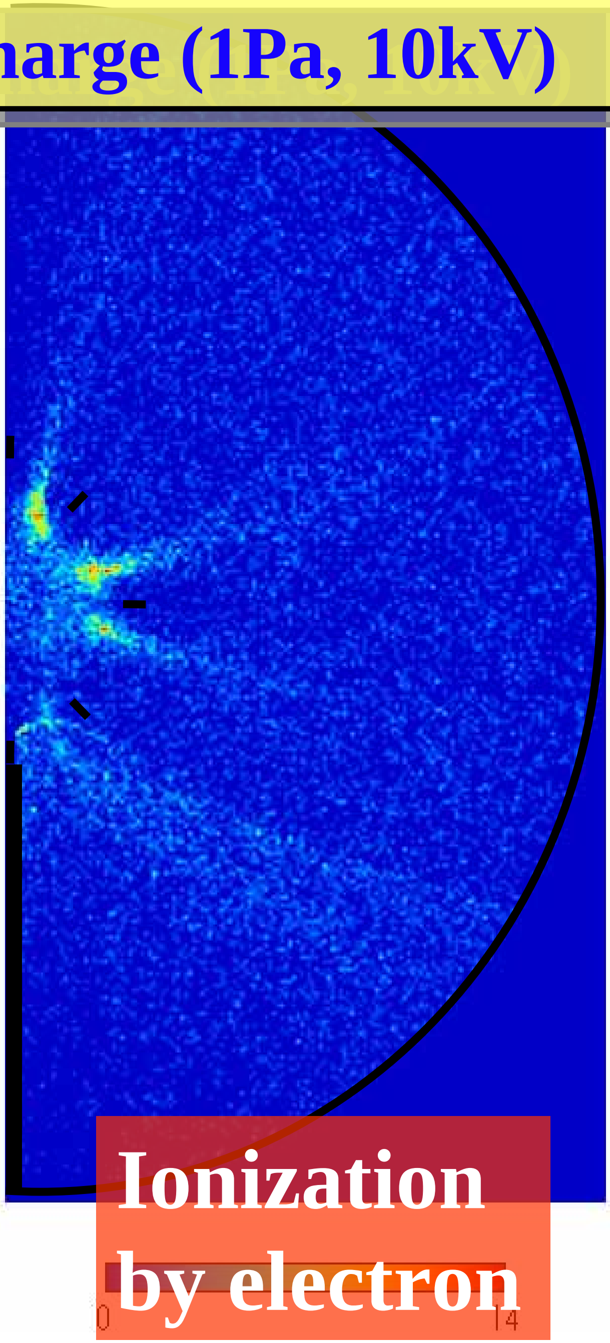
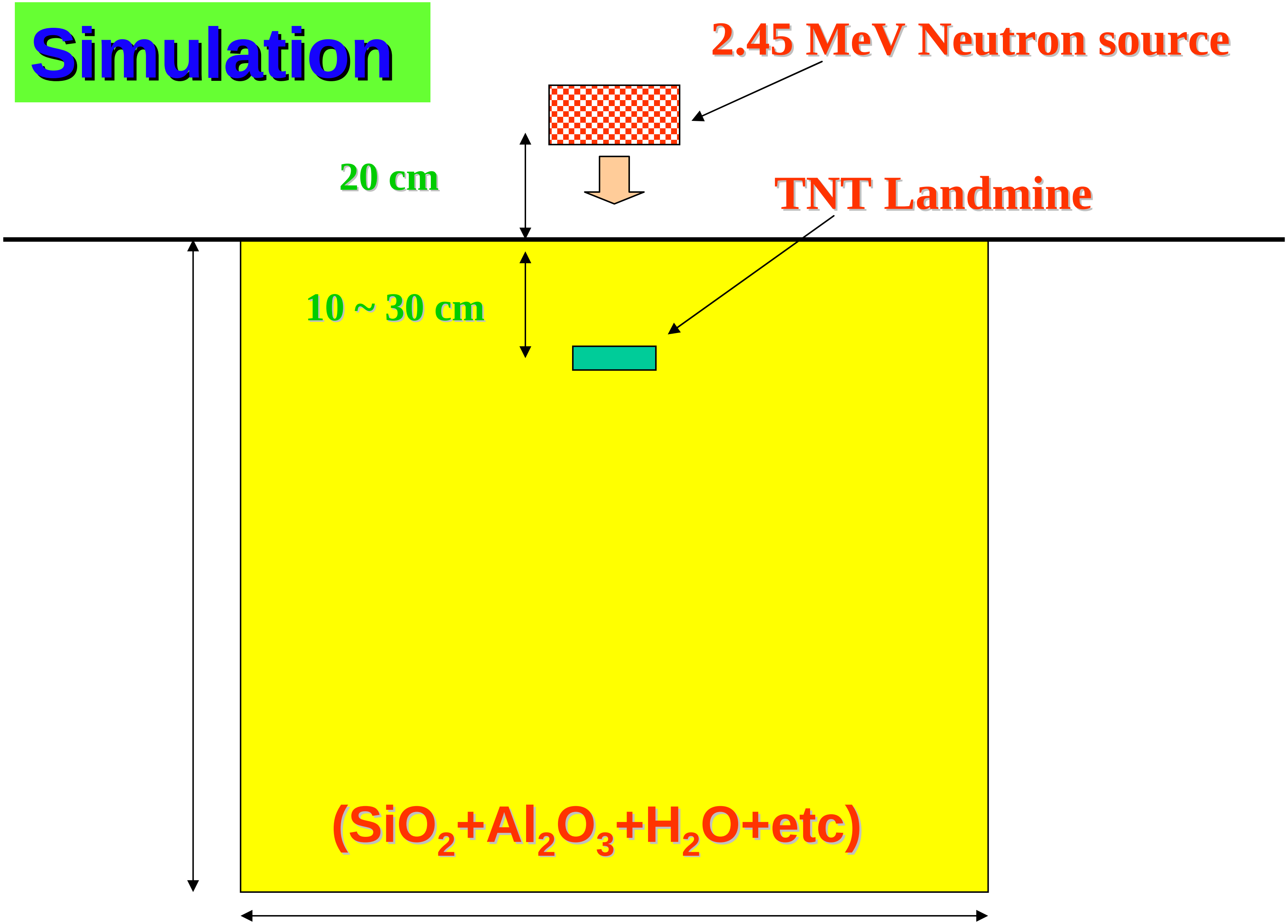


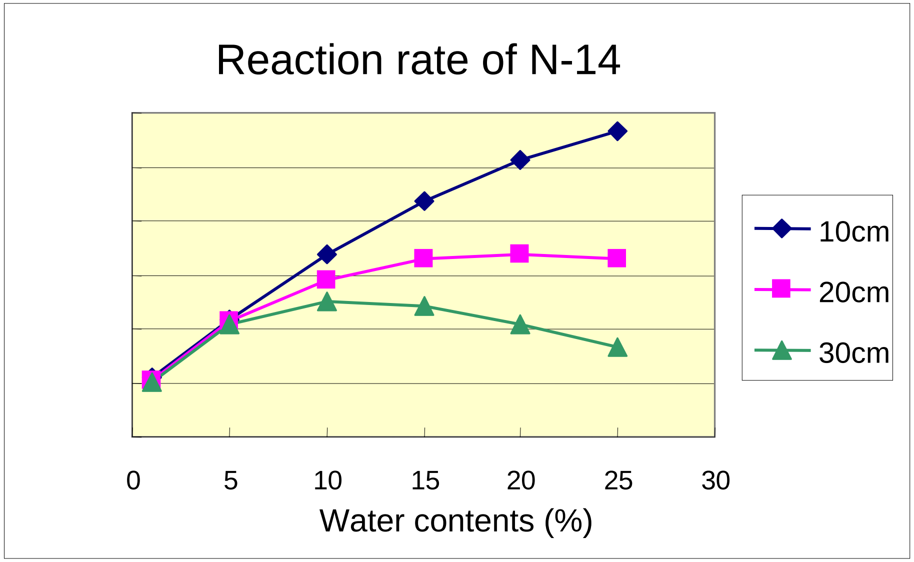
Photo of Star mode

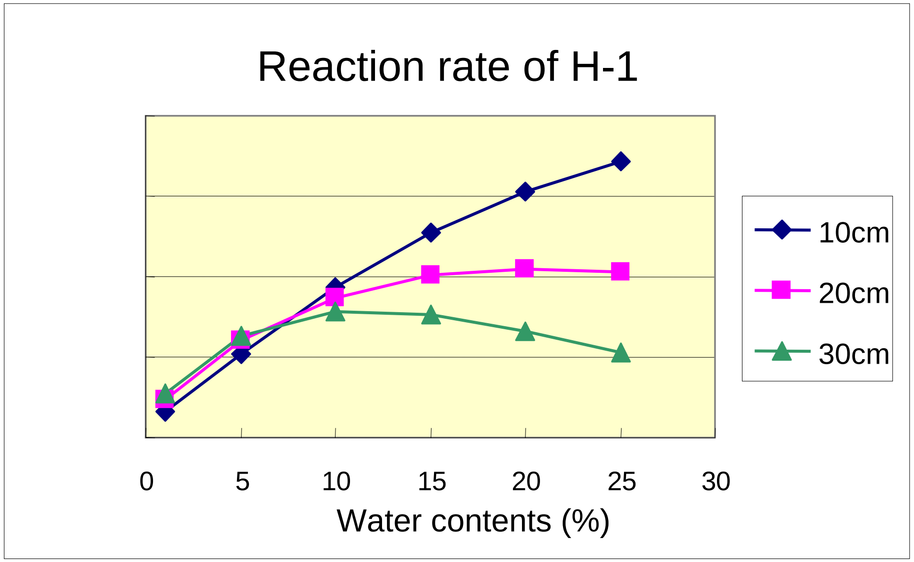


Ionization by electron

Simulation


2.45 MeV Neutron source
20 cm
TNT Landmine
10 ~ 30 cm
$(SiO_2+Al_2O_3+H_2O+etc)$

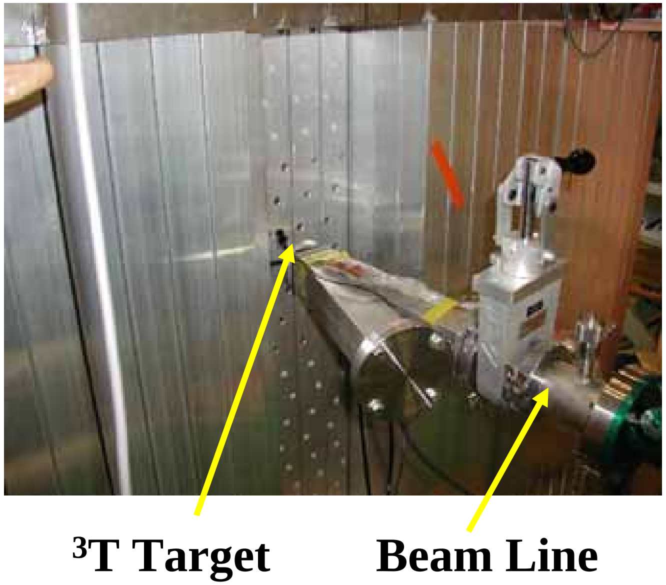


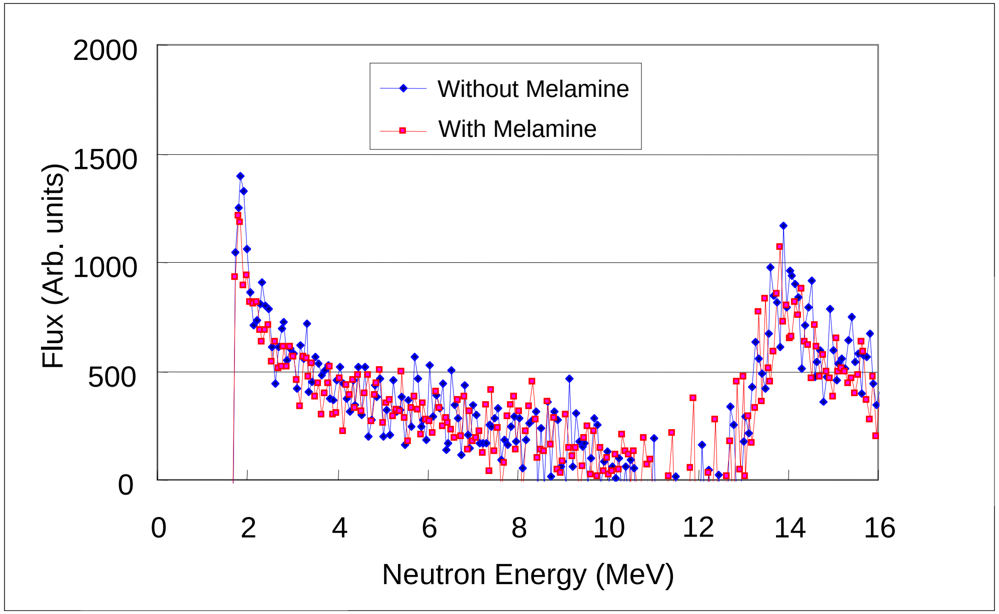


Capture reaction rate of N and H

- Largely depend on depth of landmine and water content in the ground
  - In case of shallow position, high water contents causes high capture reaction rate
  - In case of deep position, optimum water contents causes high capture reaction rate
- In case of water contents less than 5 %, reaction rate does not depend on depth.

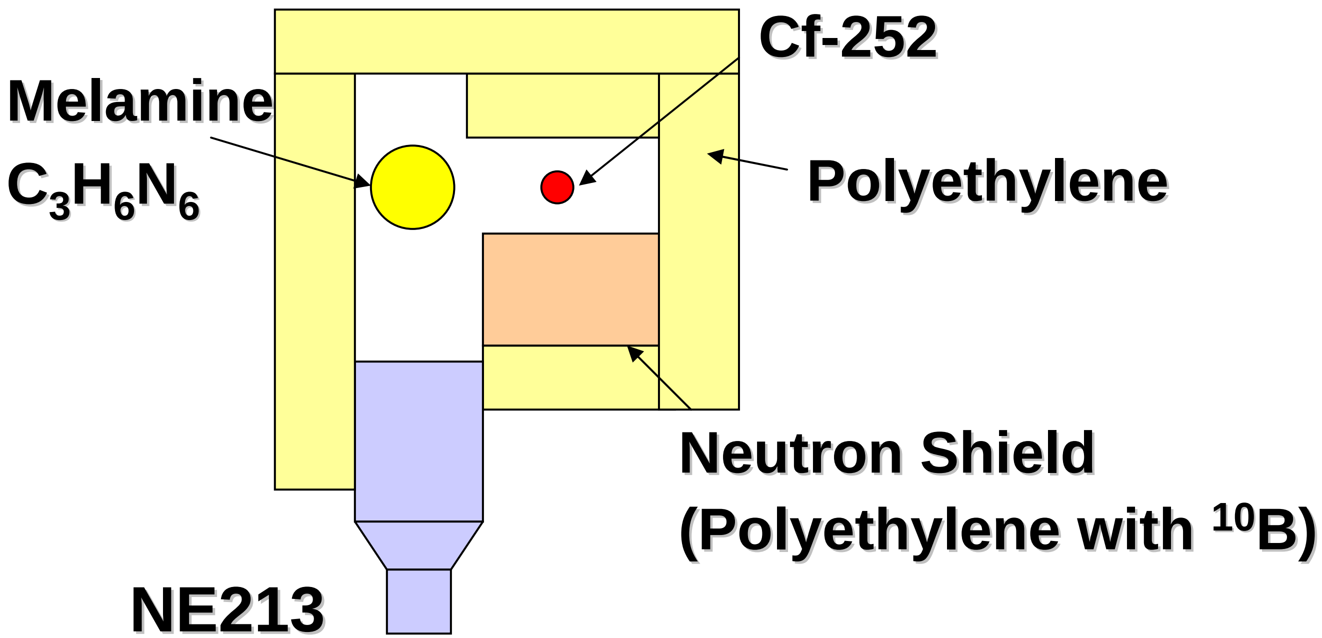
Experiment with 14MeV DT neutron source with melamine ($C_3H_6N_6$)





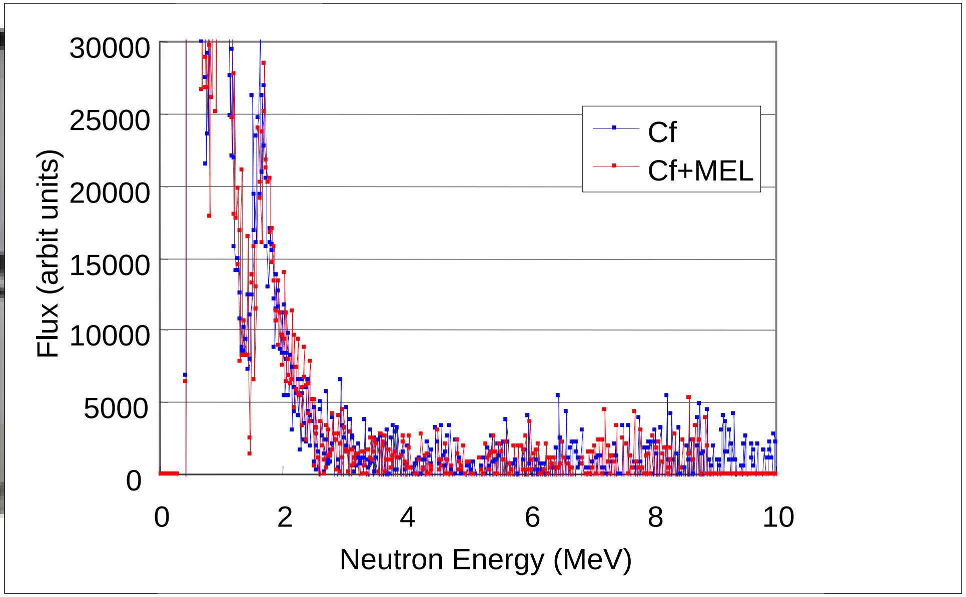
- •NE213 scintillator was used for neutron spectrum measurement
- •Low energy neutron was increased about 5 % with Melamine
- •Same as calculated results

Experiment with ^{252}Cf neutron source (1)



Experiment with ^{252}Cf neutron source (2)

Polyethylene **NE213**

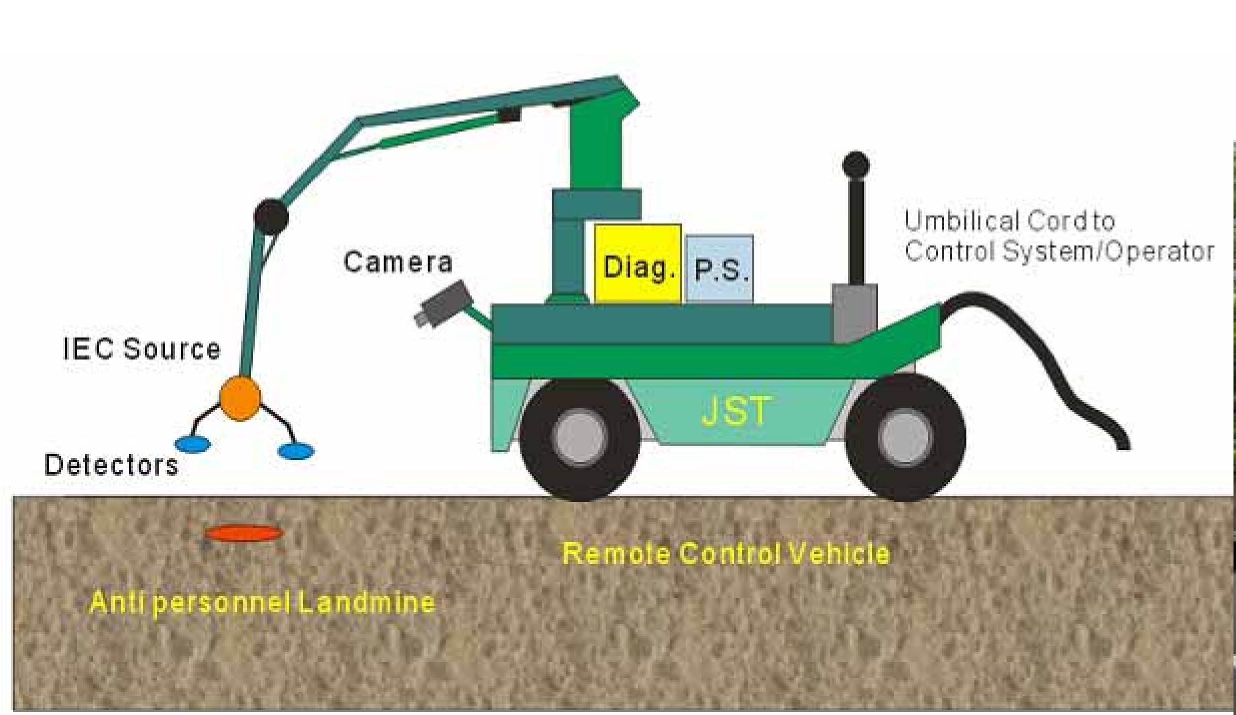


- **NE213 scintillator was used for neutron spectrum measurement**
- **Low energy neutron was increased about 4 % with Melamine**
- **Same as calculated results**

Goal of Project

Detection thru neutron-related reactions, able to identify LM with an Innovative IEC neutron source

Constituents and Location



Companion Papers

[1]K.YAMAUCHI, *et. al*., "Pulsed Operation of a Compact Fusion Neutron Source Using a High-Voltage Pulse Generator Developed for Landmine Detection", **P-II-23**, 16th TOFE (2004).

[2] T. TAKAMATSU, *et. al*., "Improvement of an Inertial Electrostatic Confinement Device", **P-II-16**, 16th TOFE (2004).

[3]H. OSAWA, *et. al*., "Optimal Position of Ion Source for High Performance of IEC", **P-II-17**, 16th TOFE (2004).

[4]H. OSAWA, *et. al*., "Numerical Study on Hollow Cathode Discharge of IEC Fusion", **P-II-18**, 16th TOFE (2004).