Overview of IEC Research at Kyoto Univ.

IEC2011
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Highlights from KU IEC Program

- RS-MIS driven IEC
  - Runs at extremely low pressure of 5 mPa
  - Upgrade plan: 1 mA (achieved) ➡ 100 mA (target)
- Neutron/X-ray two-beam radiography by use of a glow-discharge driven IEC
- Design of a pulsed high-peak IEC NG for HEU interrogation
- Multistage HV feedthrough scheme that can
  - modify spherical symmetry of E-field, and
  - prevent arcing and enable high-voltage operation.

Towards the BM-BM Fusion Regime

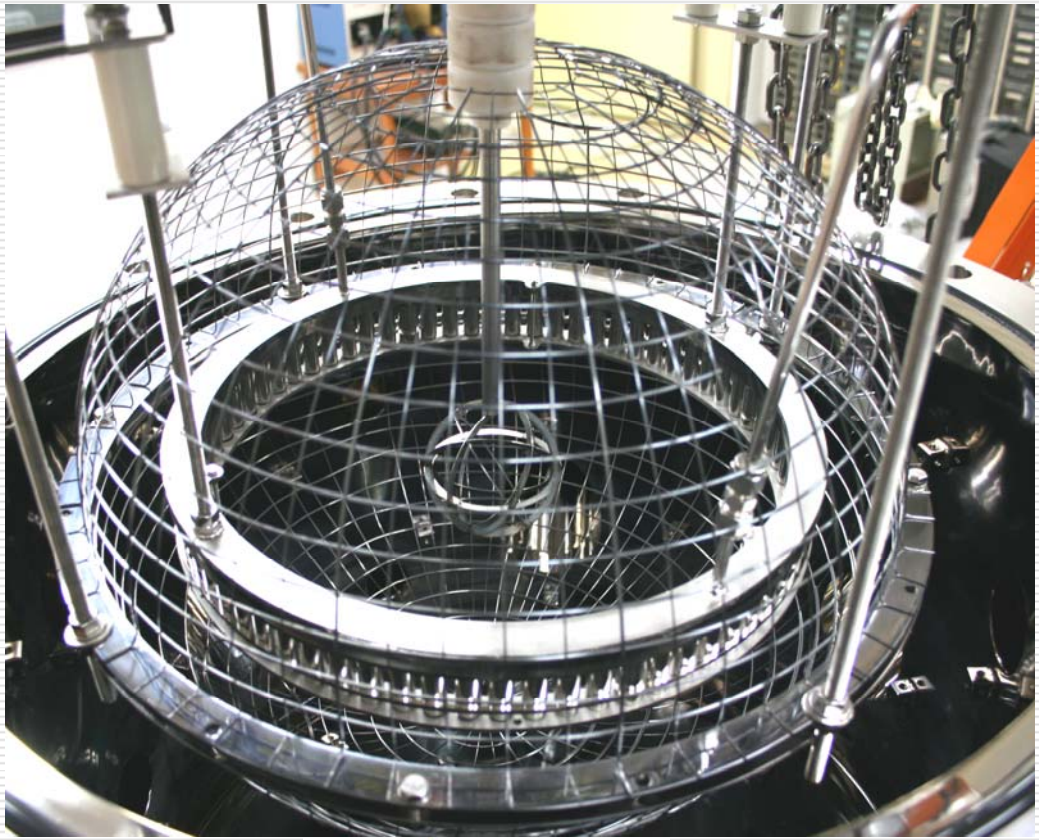
- Beam-gas and/or beam-electrode contributions are predominant in any IEC device developed so far; either glow– or ion–source–driven IEC.
- σ_{fusion} / σ_{CX} will limit NPR / Power, so long as we stay in the beam-gas regime.
- Accelerator-based neutron generator is a much better system than IEC for the beam-electrode regime.

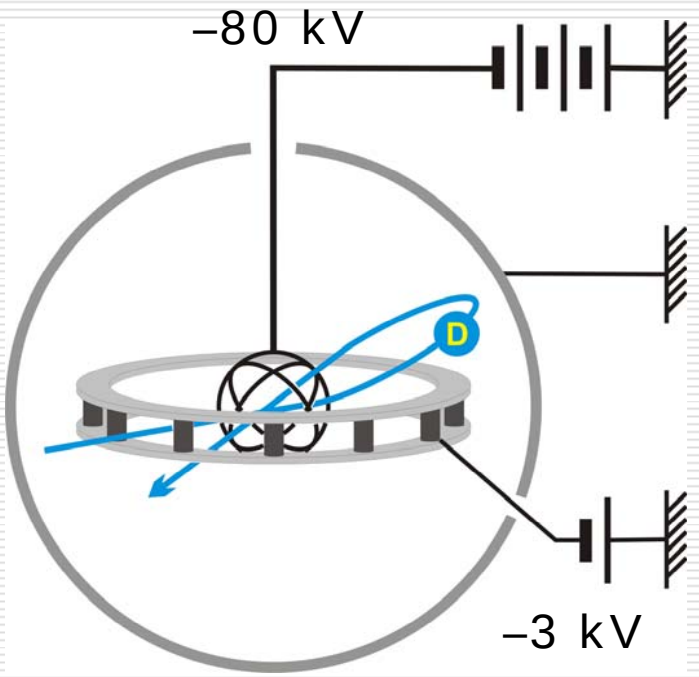
Requirements for the BM-BM regime:

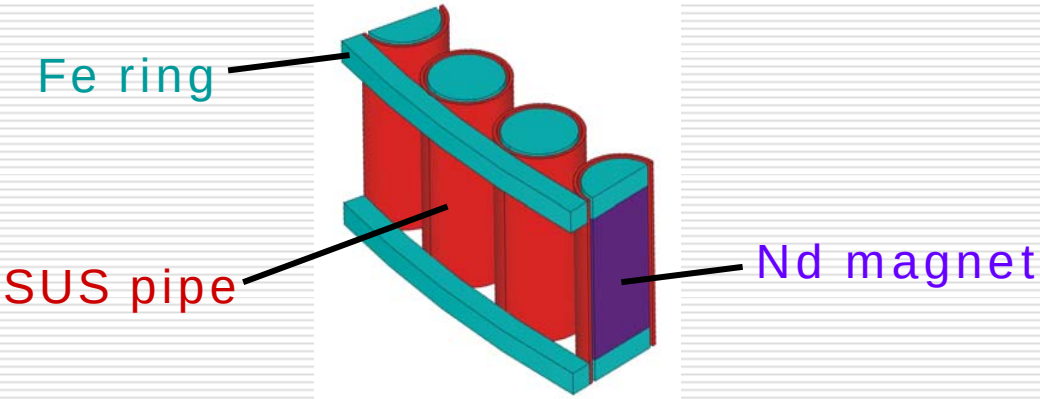
High ion density, as high as gas density, in a small volume (converged core).

- high current-to-pressure ratio, *I* / *P*
- significant ion recirculation

Ring-Shaped Magnetron Ion Source Driven IEC



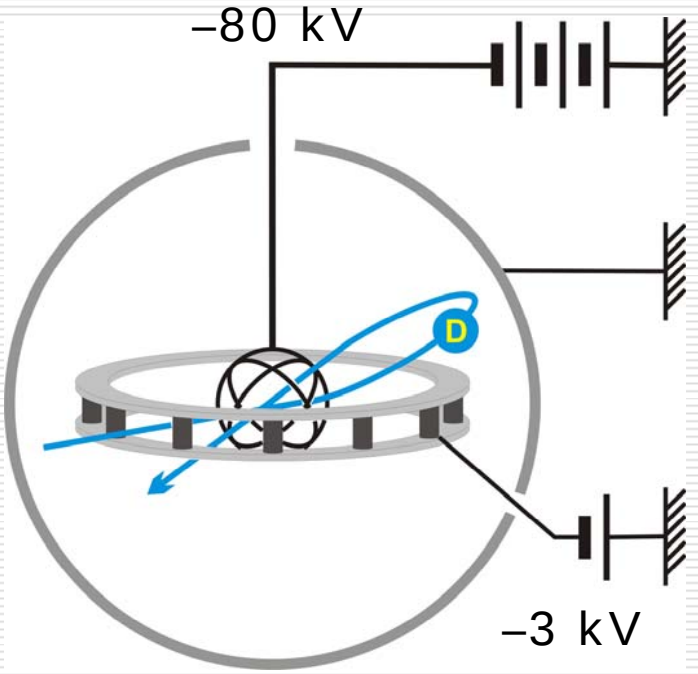


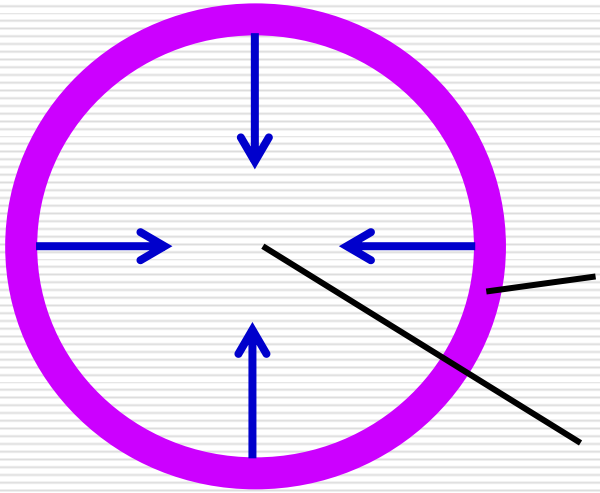


K. Masuda, T. Nakagawa, J. Kipritidis, et al., *Plasma Phys. Control. Fusion* 52 (2010) 095010.

RS-MIS Driven IEC: Features

- Extremely low pressure operation:
  - 5 mPa, 1 mA
- Birthplace of ions preferable for recirculation;
  - at negative potential,
  - normal to the HV feedthrough.
- Planar focus of ions.



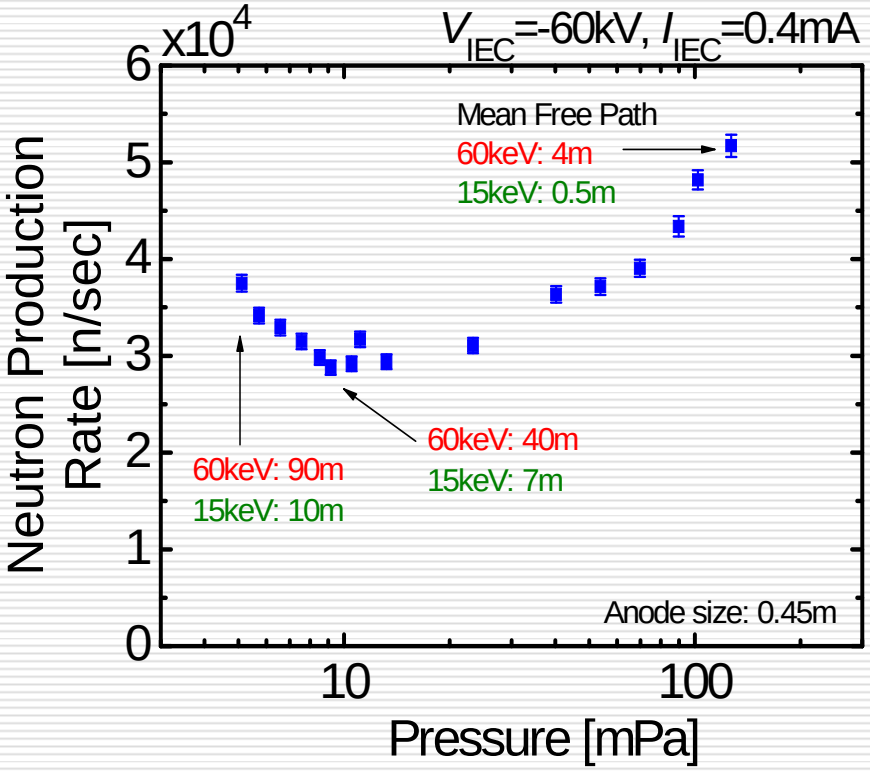


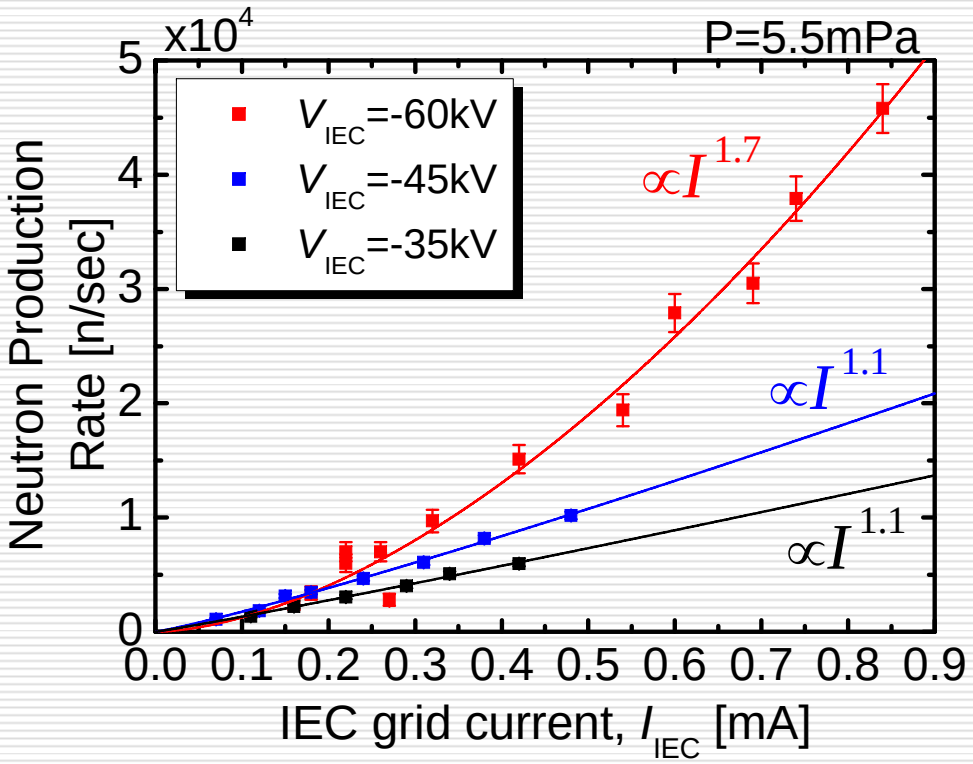
Degree of ionization in the discharge gives $n_{ion}/n_{neutral}$ in the source region.

The planar focus of ions enhances $n_{ion}/n_{neutral}$ at the converged core.

RS-MIS Driven IEC: Review

- NPR turned out to increase as the pressure decreases, for low pressure below 10 mPa.
- NPR showed nonlinear dependence on current.





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J. Kipritidis, K. Masuda et al., *Plasma Phys. Control. Fusion* 53 (2011) 045006.

RS-MIS Driven IEC: Review

- NPR turned out to increase as the pressure decreases, for low pressure below 10 mPa.
- NPR showed nonlinear dependence on current
- These phenomena are seen only temporary…
  - (Feb. 2009) NPR $\propto$ I^ 1.7 @ 60 kV, 5 mPa
  - (July 2009) 1.0 @ 60 kV, 5 mPa
  - (12 Aug 2009) 1.7 @ 80 kV, 5 mPa
  - (14 Aug 2009) 1.4 @ 80 kV, 5 mPa
  - (16 Aug 2009) 1.0 @ 80 kV, 5 mPa
- Simulation suggested that
  - confinement time of ions is dominated by BM-Grid collisions rather than BM-Gas charge exchange,
  - BM-BM NPR is 4 orders of magnitude lower than BM-Gas at 1 mA and 5 mPa,
  - Time variation of absorbed D_2 surface density on the cathode grid provides a qualitative explanation.

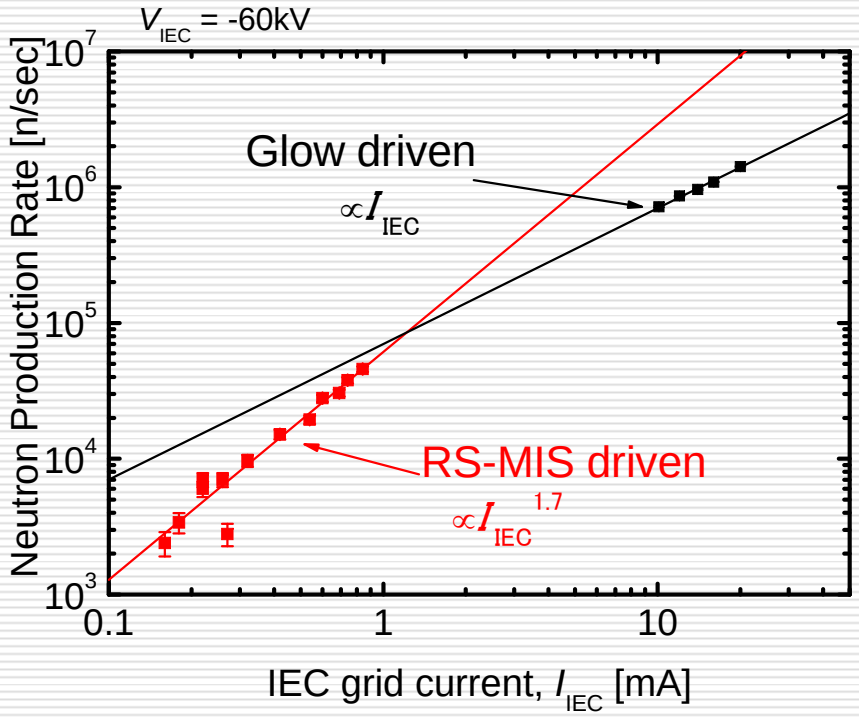
K. Masuda, T. Nakagawa, J. Kipritidis et al., *Plasma Phys. Control. Fusion* 52 (2010) 095010.
J. Kipritidis, K. Masuda et al., *Plasma Phys. Control. Fusion* 53 (2011) 045006.

RS-MIS Driven IEC: Efforts in Progress

The experimental observations of NPR dependence on *P* and *I* are still not fully explained.

- Development of a collimated proton measurement system is in progress.
- Upgrade of the RS-MIS for high-current operation is planned.

1 mA ➡ 100 mA @ 5mPa



RS-MIS Driven IEC: New Efforts in Progress

The experimental observations of NPR dependence on *P* and *I* are still not fully explained.

- Development of a collimated proton measurement system is in progress.
- Upgrade of the RS-MIS for high-current operation is planned.

  1 mA ➡ 100 mA @ 5mPa

  Presented by T. Kajirwara tomorrow morning

- Improvement of ion confinement time τ by modification of the E-field symmetry is also planned by use of a multistage HV feedthrough.

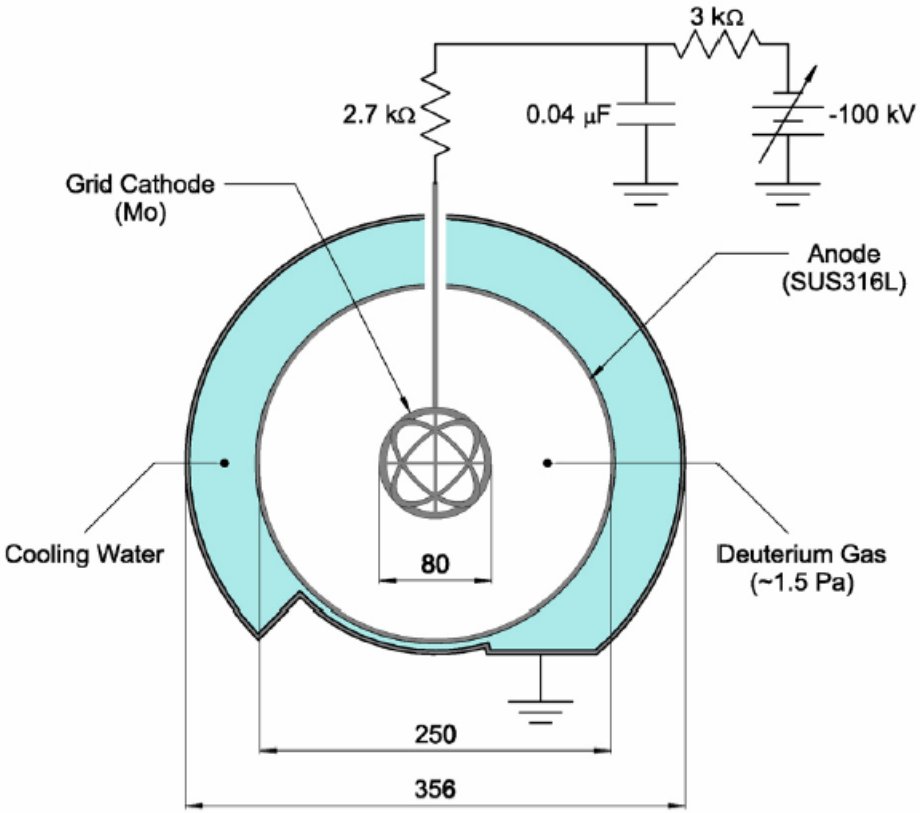
  BM-BM nonlinear dependence on τ

  BM-Gas linear dependence on τ

  BM-Gird independent of τ

  Presented by Y. Yamagaki tomorrow morning

IEC25: A glow-discharge driven compact IEC



- Developed originally for the LM-detection project.
- Provides stable neutron output of 5×10^{7} sec^{-1}.
  - Anode water-cooling enables continuous 8-hr operation.
  - NPR stabilized by FB control.
- Easy to operate.

  A student can run it after 1-day instruction.

IEC25: Application to Radiography

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IEC as a radiography source:

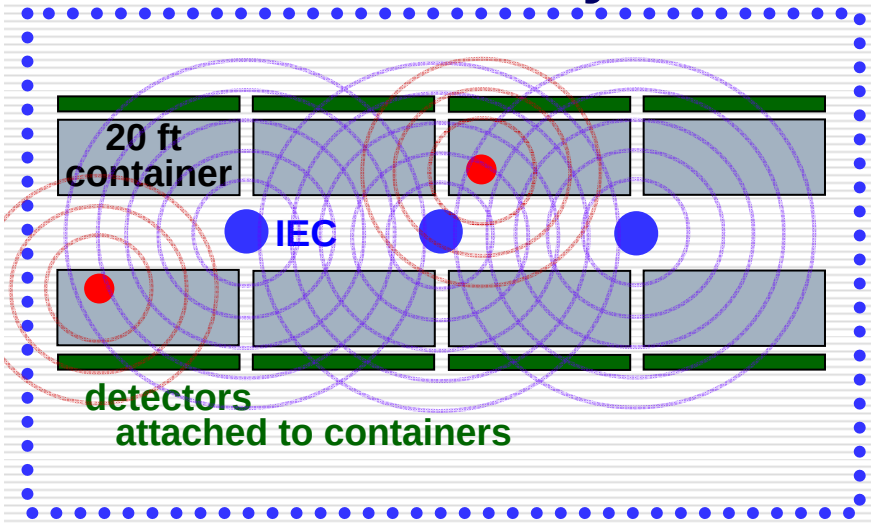
- too low NPR to use a good collimator,
  cf. fission reactor
- volume source,
  cf. accelerator-based NG
- but still applicable for thin objects.
- an advantage is that...

Proposal of Two-Beam Radiography by IEC

- Two-beam radiography is sensitive to material composition through “R-value”.
- The R-value is given by the ratio of transmittances of the two beams, which is independent of the material density and the object thickness.
- The R-vaule is much sensitive for a neutron/X-ray system than a two-color X-ray system.

HEU Interrogation R&D Project

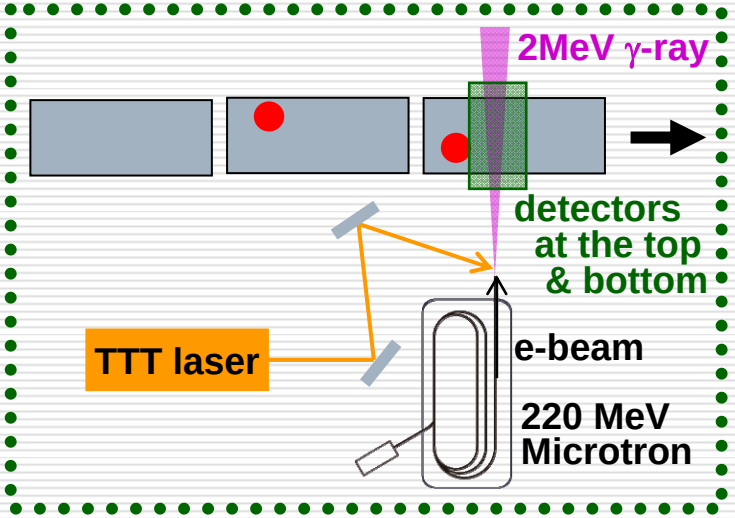
neutron-based system



40/day

360/day

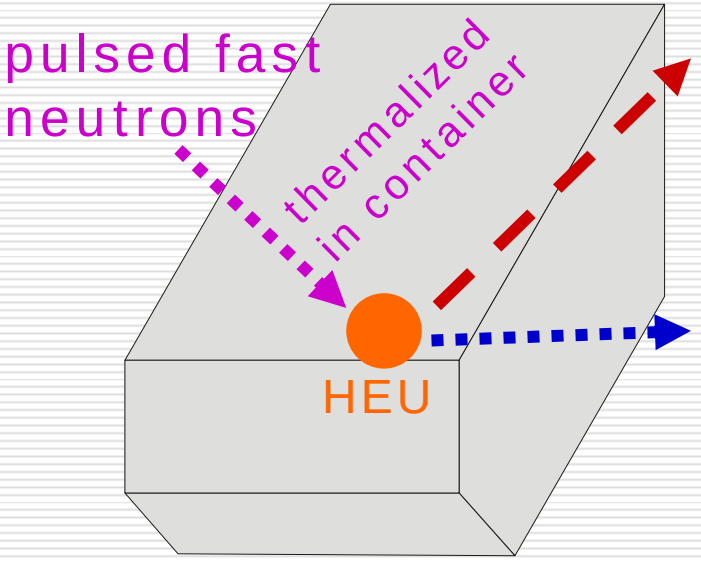
γ-ray-based system



- "isotropic probe"
  - poor spatial resolution
  - can handle many containers simultaneously
- "pencil-like probe"
  - high spatial resolution
  - high S/N ratio
  - poor scanning speed

- Estimated cost: 12.5M$
- R&D Budget: 5.5M$ (1.1M$ for neutron-based system)
- 5-year R&D from FY2010
- mid-term evaluation after 3 years

Neutron-Based SNM Interrogation



delayed neutron (~1%)

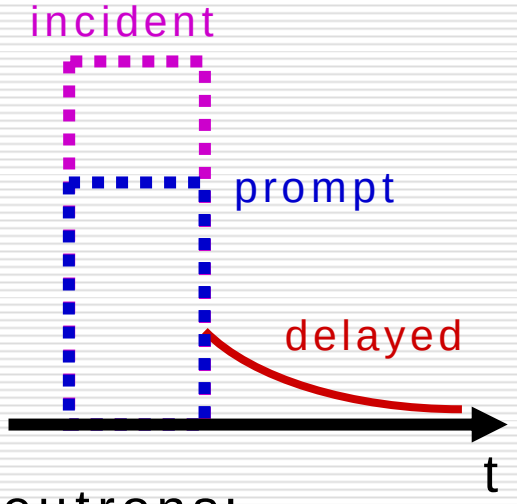
high S/N without BG

a few signals

prompt neutron (>99%)

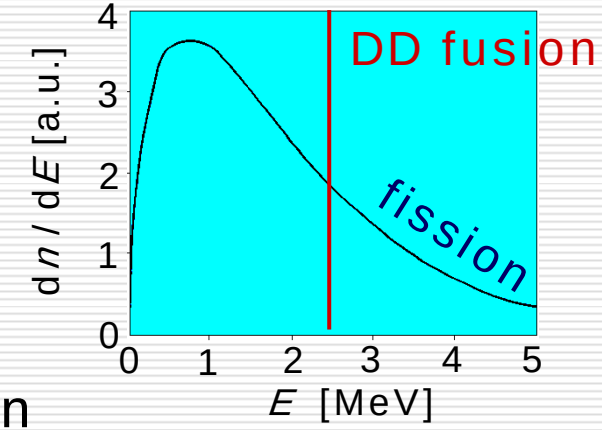
need to separate
incident and fission neutrons:

- Feynman – α method
- Differential Die-Away Analysis



Advantages of DD over DT

- No need of tritium handling
  - easy operation, easy maintenance
  - safe even in case of attack by terrorist
- Lower energy of neutrons
  - we need thermal neutrons to induce fission
  - less shielding load
  - less difficulty in separating out from fission neutrons



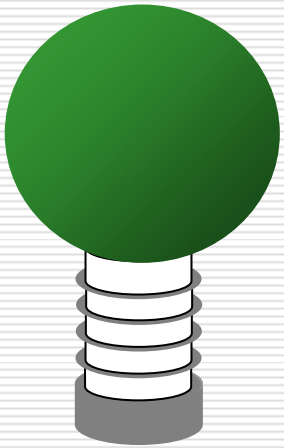
IEC & PS for the SNM Interrogation System

Neutron Generator

- DD, not DT
- pulsed peak NPR > 10^{11} sec^{-1}
- ϕ600 mm spherical IEC.
- 200 kV, 5Apeak glow-discharge
- Ti-coated electrodes
- ϕ200 mm multistage HV feedthrough to prevent arcing

dc HV test is being made
Presented by Y. Yamagaki
tomorrow morning

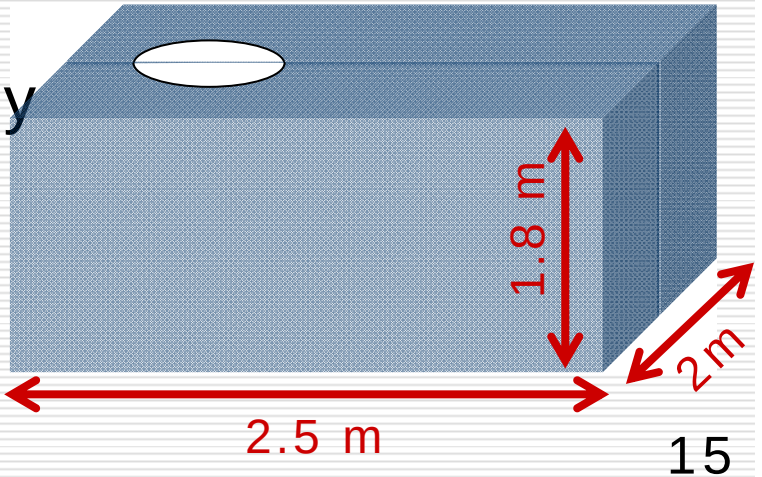
IEC employing a multistage feedthrough



Pulsed High-Voltage Power Supply

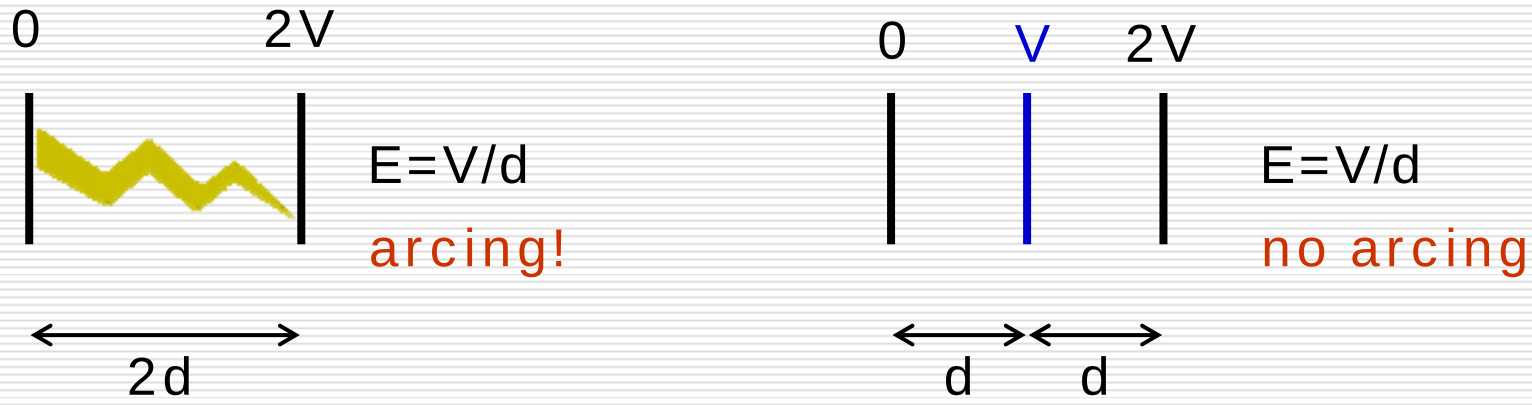
- 200 kV, 5A
- 1 – 100 μsec variable, 50 pps max.
- everything in a monocoque oil tank

➡ no EM-noise emission



IEC Employing a Multistage HV Feedthrough

- The addition of intermediately biased electrode prevents arcing.

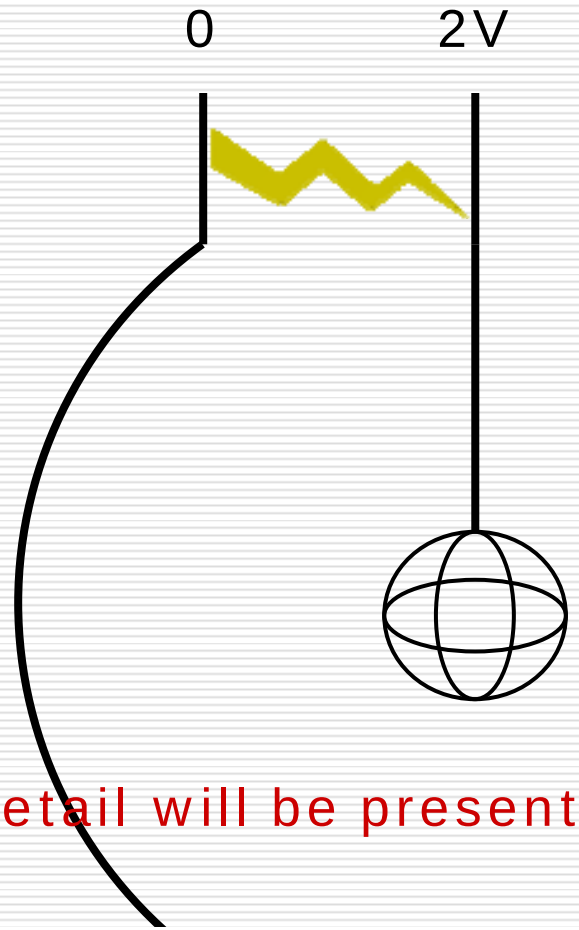


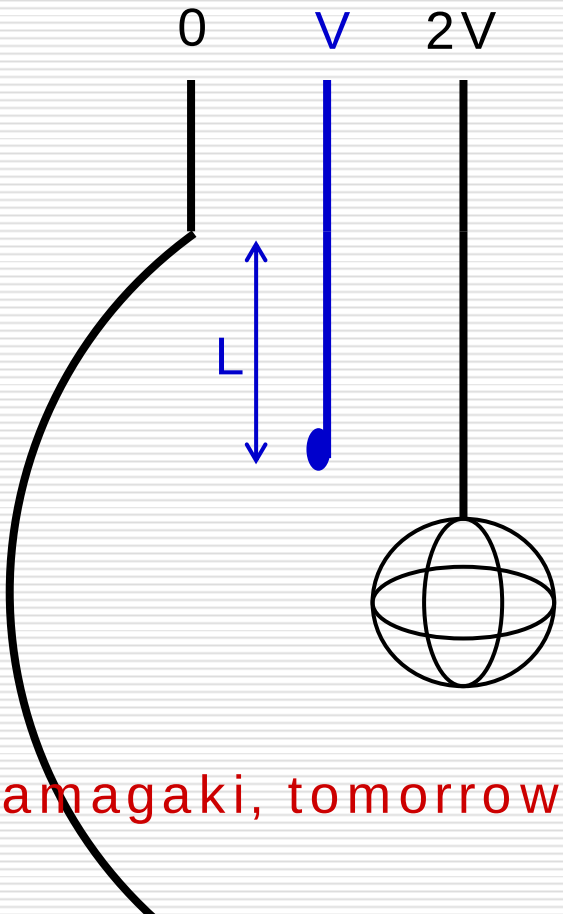
because the threshold surface E-field depends on d.

empirical law: $E_{sh} \propto d^{-3/10}$

IEC Employing a Multistage HV Feedthrough

- The addition of intermediately biased electrode prevents arcing.
- E-field distribution can be modified by changing the length L of the intermediately biased electrode.





Detail will be presented by Y. Yamagaki, tomorrow morning.

Summary

- RS-MIS IEC for BM-BM study
- Glow IECs for applications
  - IEC25: DD dc 5 x 10^{7} sec^{-1} (achieved)
  - IEC60: DD pulsed 10^{11} sec^{-1} (target)
- Applications:
  - SNM interrogation
  - neutron/X-ray two-beam radiography

Acknowledgements

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