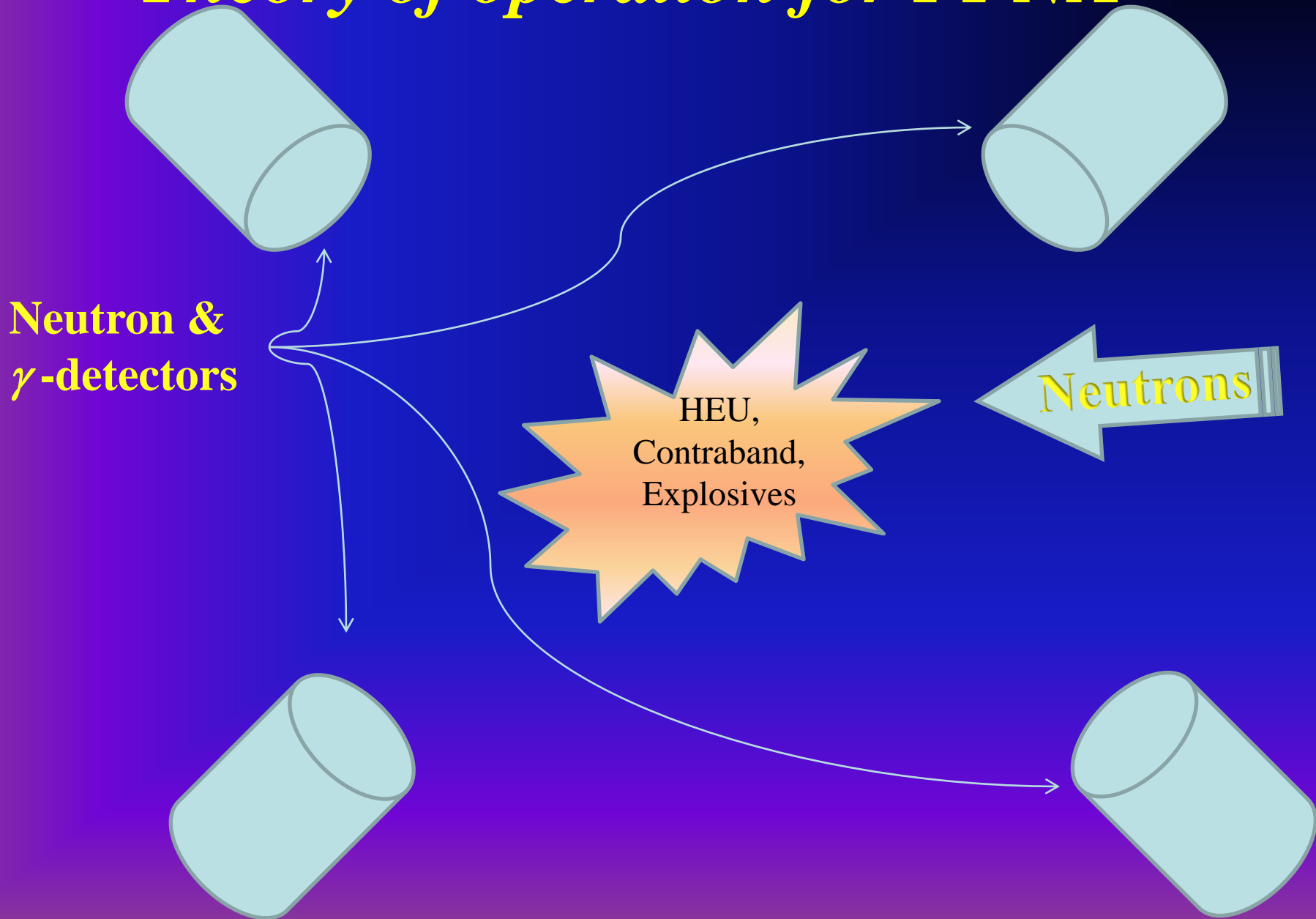




# Neutron Generators



# *Theory of operation for PFNA*



# *Where are the neutrons from?*

- Neutron generator
- Nuclear reactions to produce neutrons
  - $\text{D} + \text{D} \Rightarrow {}^3\text{He} + \text{n}$  (2.45 MeV)
  - $\text{D} + \text{T} \Rightarrow {}^4\text{He} + \text{n}$  (14.1 MeV)
- Sheffield & Glasgow collaborating
- Need such a generator!

# *Which companies are now involved?*

- VNIIA, Russia, *proposing 5 generators*
- Sodem, France, *proposing 2 generators*
- NSD Fusion, Germany, *proposing 1 generator*



# *What issues need addressing?*



- Type of reaction (neutron energy)
  - D-D  $\Rightarrow$  2.5MeV
  - D-T  $\Rightarrow$  14.1MeV
- Pulsed neutron source – what pulse duration? (TOF)
- Neutron emission (# of neutrons per pulse)
- Cost
- Other issues
  - Replaceable parts & suitable guarantees
  - Disposal of active heads at end of lifetime
  - Option to use DD & DT
  - Quick delivery
  - Dimensions of the generator package



# *VNIIA, Russia...*

## *The “INGs” – an overview*

- ING-10, ING-12, ING-013, ING-03, ING-031
- All DD & DT
  - DD  $\Rightarrow 6 \times 10^4 - 6 \times 10^6$  n/pulse
  - DT  $\Rightarrow 6 \times 10^6 - 10^8$  n/pulse
- ING-10 & 12 have sub  $\mu$ s pulses
  - (300 & 400 ns resp.)
- 013, 03 & 031 have  $< 1.2 \mu$ s pulses
- \$: 30k, 35k, 50k, 53k, 56k respectively.
  - “Running cost of equip. \$20k, incl. commissioning & training”
  - Available parts after lifetime (disposal not included)
- 4-6 months delivery time

# *VNIIA, Russia...*

## *The “INGs” in more detail*

### ➤ **ING-10 (\$30,000 ~ £18,000)**

- $DD = 10^5$ ,  $DT = 2 \times 10^7$ ; 300ns
- $10^7$  pulses as tube lifetime
- 70W power consumption
- 34mm (diam.) x 1320mm

### ➤ **ING-12 (\$35,000 ~ £21,000)**

- $DD = 2.5 \times 10^5$ ,  $DT = 5 \times 10^7$ ; 400ns
- $10^7$  pulses as tube lifetime
- 120W power consumption
- 49mm (diam.) x 1000mm

# *VNIIA, Russia...*

## *The “INGs” in more detail*

- **ING-013** (\$50,000 ~ £30,000)
  - $DD = 6 \times 10^4$ ,  $DT = 6 \times 10^6$ ;  $\leq 1.2 \mu s$
  - $5 \times 10^6$  pulses as tube lifetime
  - 500W power consumption
  - Control pulse (0.1 Amplitude)  $\sim 5 \mu s$
  - 1000mm tube unit (? diam)
  
- **ING-03** (\$53,000 ~ £32,000)
  - $DD = 5 \times 10^5$ ,  $DT = 5 \times 10^7$ ;  $\leq 1.2 \mu s$
  - $5 \times 10^6$  pulses as tube lifetime
  - 500W power consumption
  - Control pulse (0.1 Amplitude)  $\sim 5 \mu s$
  - 1000mm tube unit (? diam)

# *VNIIA, Russia...*

## *The “INGs” in more detail*

- **ING-031** (\$56,000 ~ £34,000)
  - $DD = 10^6$ ,  $DT = 10^8$ ;  $\leq 1.2 \mu s$
  - $5 \times 10^6$  pulses as tube lifetime
  - 800W power consumption
  - Control pulse (0.1 Amplitude)  $\sim 5 \mu s$
  - 1000mm tube unit (? diam)

# *EADS Sodern – Genie 16 C & 16 GT*

- DD or DT options (delivery time differs)
  - 4(DT) – 7(DD) months delivery time
- €: 90k for either 16C / 16GT (~£80,000) **excl VAT!**
- **Other costs added (delivery, training, etc)**
  - 2days at EADS or 3days on-site
- Disposal included (shipping IS required)
  
- $2 \times 10^8$  neutrons/sec/ $4\pi$ sr (DT)
- $2 \times 10^6$  neutrons/sec/ $4\pi$ sr (DD)
- Tube lifetime >4000 hours

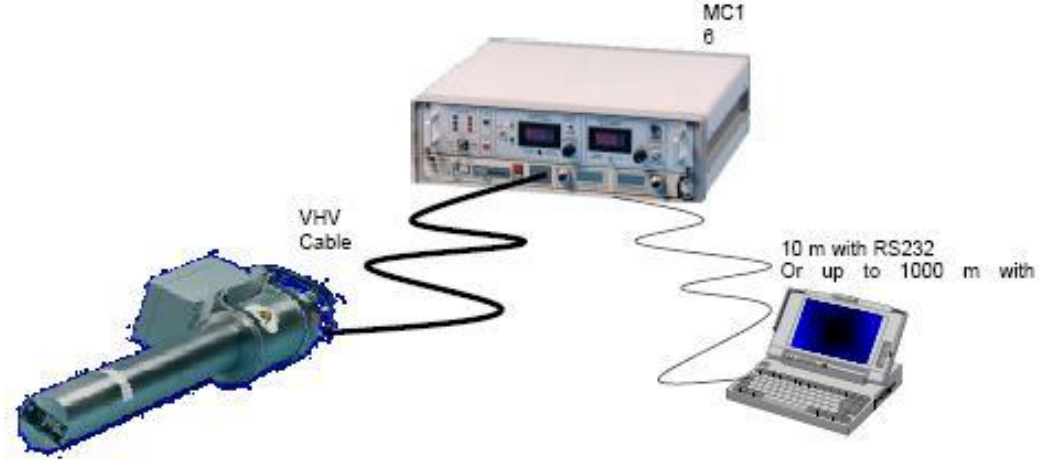
# *EADS Sodern – Genie 16 GT*

- 120GBq tritium
- 76mm (diam.) x 525mm + 104mm (diam.) x 215mm
- “neutron pulse rise and fall time  $<1.5\mu\text{s}$ ”
- 10Hz - 10kHz repetition rates

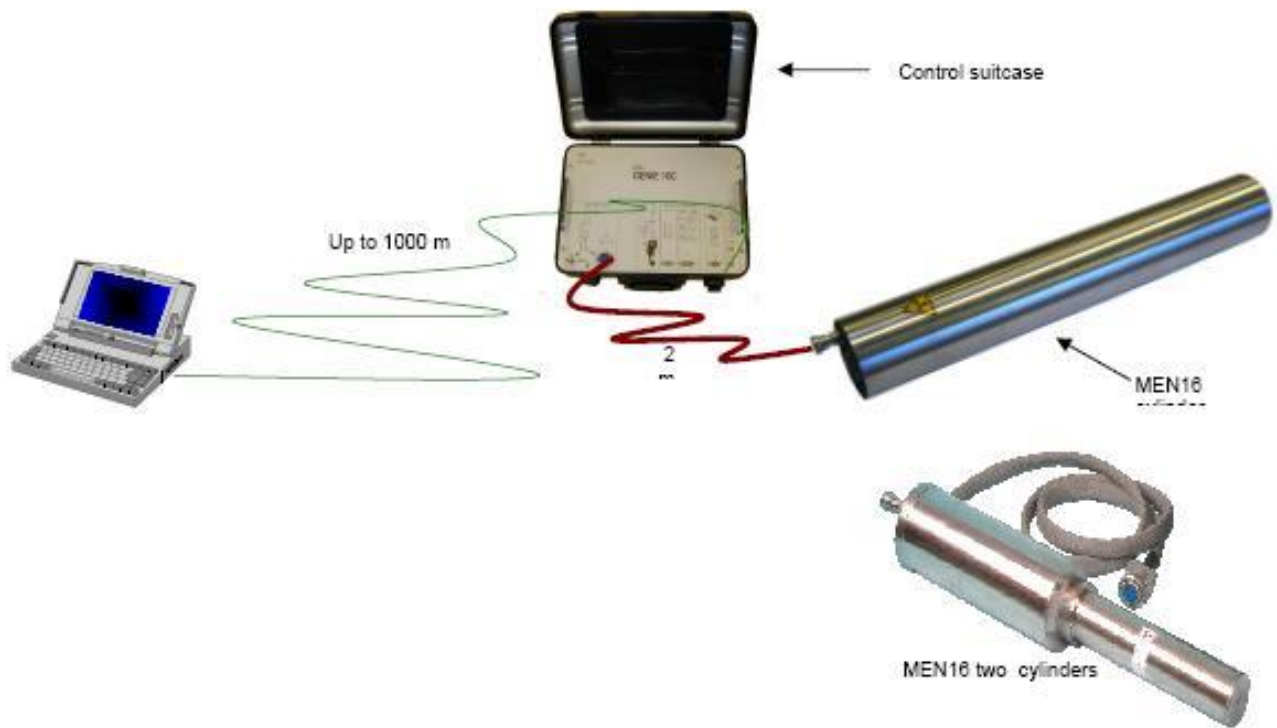
# *EADS Sodern – Genie 16 C*

- 120GBq tritium
- 65mm (diam.) x 315mm + 115mm (diam.) x 318mm
- “neutron pulse rise and fall time  $<1.5\mu\text{s}$ ”
- 10Hz - 10kHz repetition rates

➤ 16GT



➤ 16C



# *NSD Fusion – NG1e7DD, NG1e9DT*

- DD yielding  $10^7$  neutrons/sec into  $4\pi$ sr
- 100Hz-10kHz rep rate
- 20,000 hour lifetime
- **Pulse Duration  $20\mu\text{s}$**  (can be decreased to  $4\mu\text{s}$ )
- €105,000 ~£95,000
- Delivery ~ 6 months

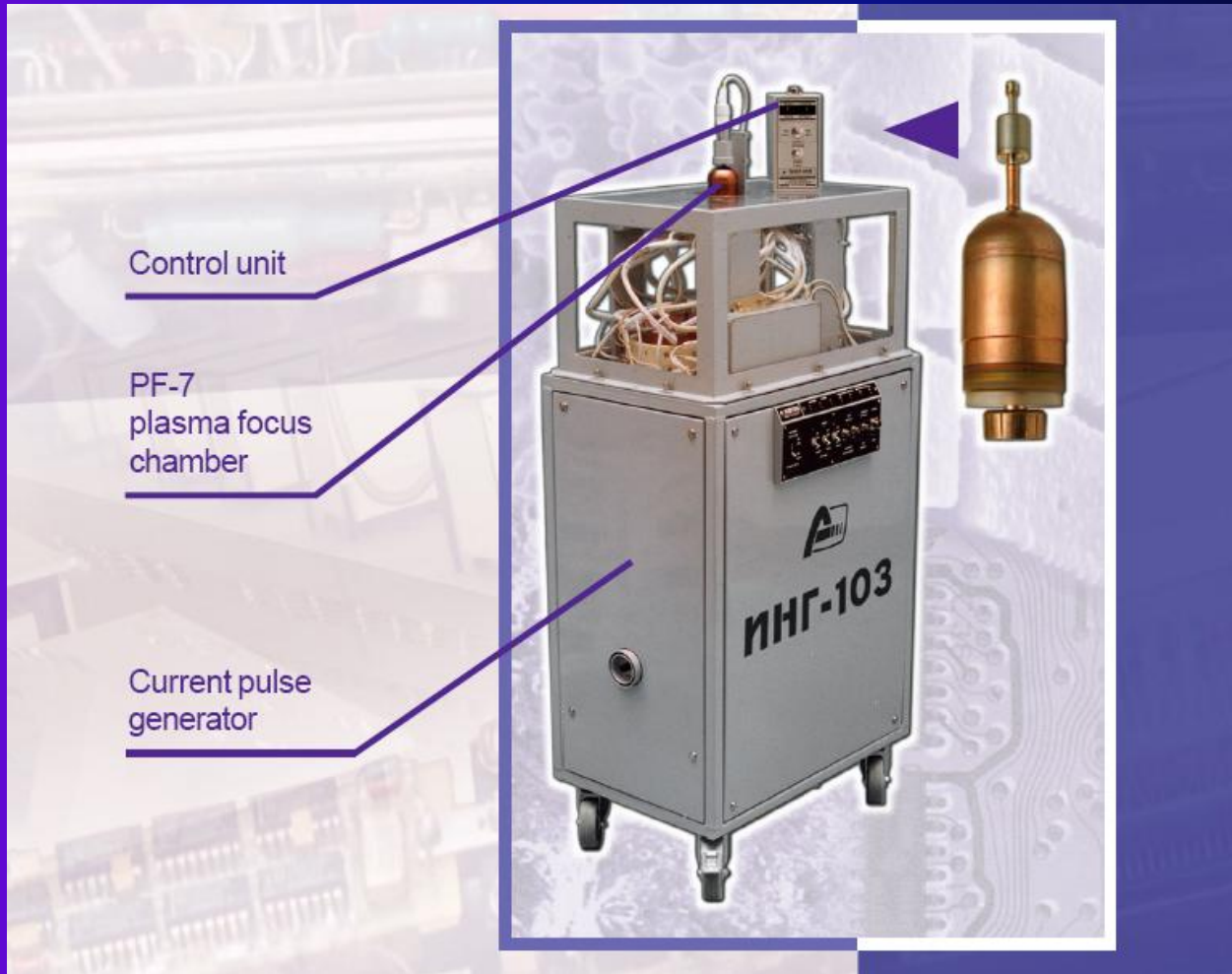
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- 20,000 hour lifetime
- **Pulse Duration  $20\mu\text{s}$**  (can be decreased to  $4\mu\text{s}$ )
- €105,000 ~£95,000
- Delivery ~ 6 months

# *Other Options?*

- VNIIA offer shorter pulse durations (10-30ns)
  - ING-102, ING-103, ING-104
- EADS Genie-35: 100x more output in DD & DT
- Reopen tender?

# ING - 103



- Pulse duration of 20ns
- 250kg!

# Summary

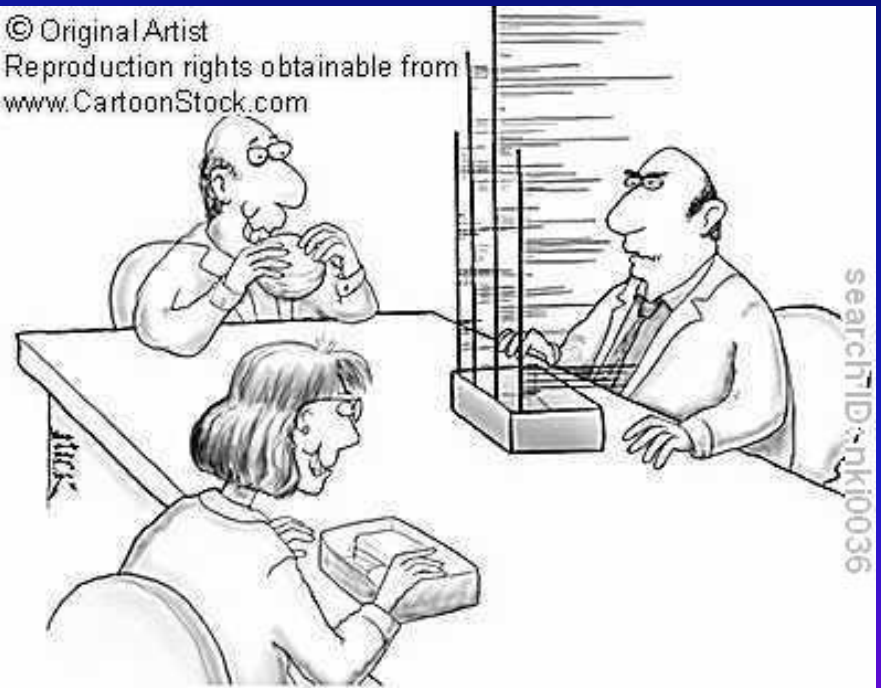
- Seen a quick insight to the means of NAA
- Discussed the neutron generators available to UOS
- Prices range from £18,000-£95,000!
- Need to decide which parameters are most important



# Dr Frankenstein's GM FOOD MART



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*"Okay—who put my lunch through the mass spectrometer..?"*