MANDI

A Mobile Accelerator-Based Neutron Diagnostics Instrument

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Project Summary

- Study technical feasibility of invasion-free content scanning/analysis by fast-neutron imaging techniques
- Use a mobile commercial n generator/scanner
- Study absorption, scattering, amplification, and transport of fast neutrons (2.5, 15 MeV) through macroscopically thick targets of various materials, including fissile materials such as U and Pu isotopes
- Develop computer simulation models for neutron transport.

Much of the US import from around the world arrives in large containers . Estimate: Less than 2% of these containers are inspected for undesirable content (weapons, ammunition, fissile materials etc).

What is Needed: Content Analysis
→ Fast-Neutron Imaging

Inspection of large containers

- Non-invasive imaging of contents
- Specific to materials
  (heavy metals, fissile materials)
- Mobile inspection instruments
- Economical construction and operation

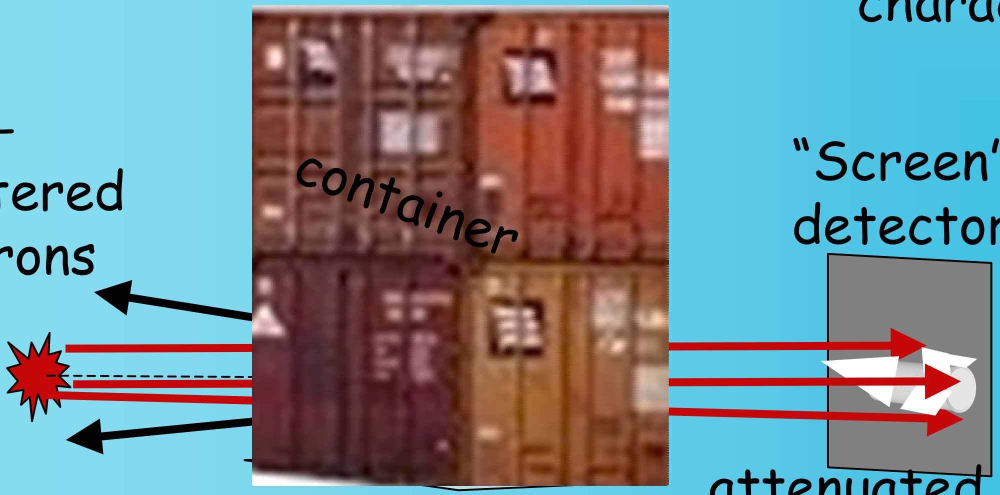
Use penetrating n-radiation

→absorption and attenuation

→back scattering

of neutrons by dense/heavy materials

→emission of characteristic γ– rays



back-scattered neutrons

container

Neutron source

"Screen" detector

shadow of massive hidden object

attenuated beam of transmitted neutrons

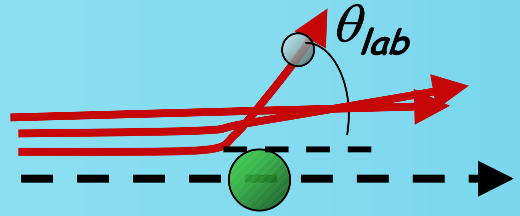
Principle of Fast-Neutron Imaging (1)

For a survey over related issues see: "The Practicality of Pulsed fast Neutron Transmission Spectroscopy for Aviation Security", National Materials Advisory Board, (National Academy Press, NMAB-482-6, 1999)

Properties of n scattering depends on the sample mass number *A*

➔ Measure time-correlated flux of transmitted or reflected neutrons

Light Nucleus



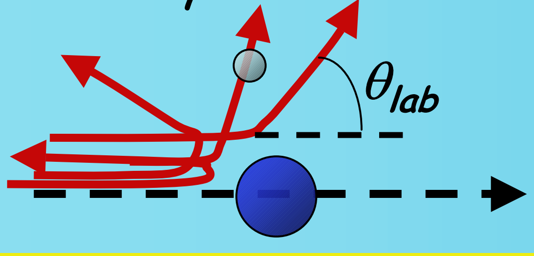
$$\langle \cos\theta_{lab} \rangle = 2/(3A) \propto A^{-1} \quad average$$

$$\langle \theta_{lab} \rangle \sim \frac{\pi}{2} - \frac{2}{3A}$$

$$E_f(N) \approx E_i \cdot \exp\left\{ \frac{-2N}{(A + 2/3)} \right\}$$

$$(After\ N\ collisions)$$

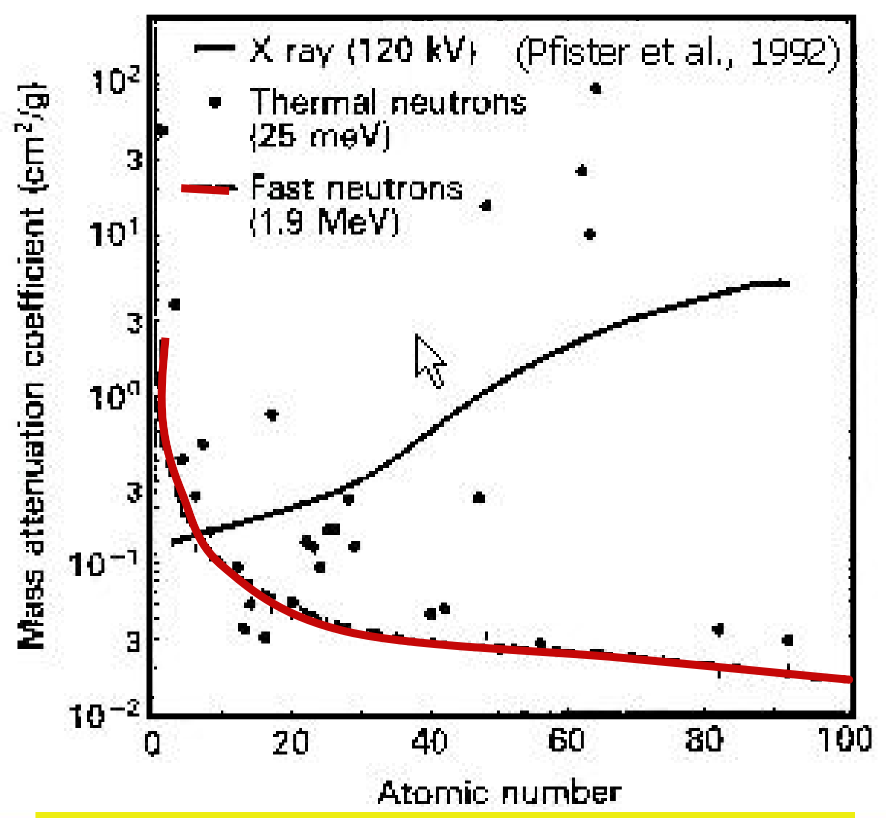
Heavy Nucleus



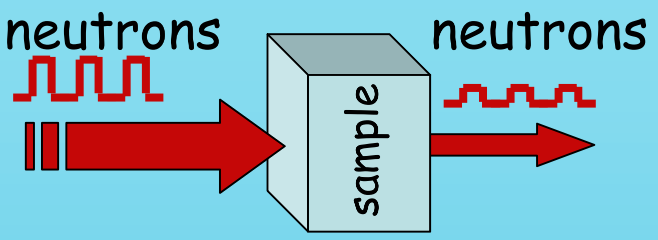
Light nuclei: slowing-down and dispersion of neutron flux, little reflection

Heavy nuclei: little energy loss of neutrons, high reflection/transmission

Principle of Fast-Neutron Imaging (2)



Transmission decreases exponentially (reflectivity increases) with thickness and density of sample, for most materials.



ϕ(0) → δ ← ϕ(δ)

incoming transmitted

$$\phi(\delta) = \phi(0)\cdot T(\delta)$$

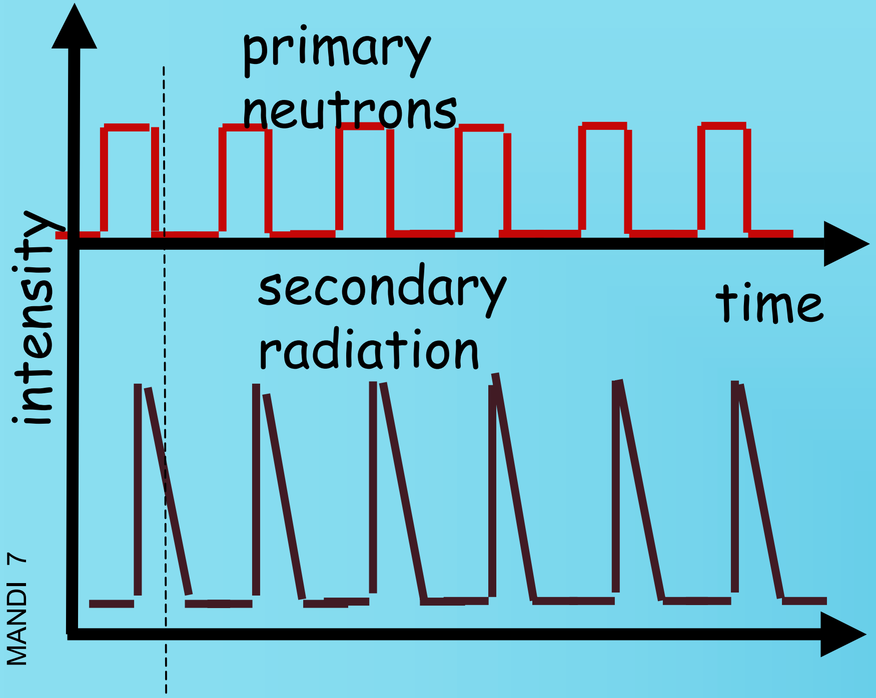
$$T(\delta) = e^{-\Sigma\cdot\delta} \quad Transmission$$

$$\Sigma = \mu\cdot\rho = N_A\cdot\sigma_A\cdot\rho$$

$$\mu = atten.coeff$$

$$\rho = material\ density$$

Principle of Fast-Neutron Imaging (3)



Neutron interactions with sample nuclei may produce **characteristic secondary radiation:**

1. γ-rays (n, γ)
2. charged particles (n, α),…
3. neutrons (n,n′)
4. fission fragments (n,f)

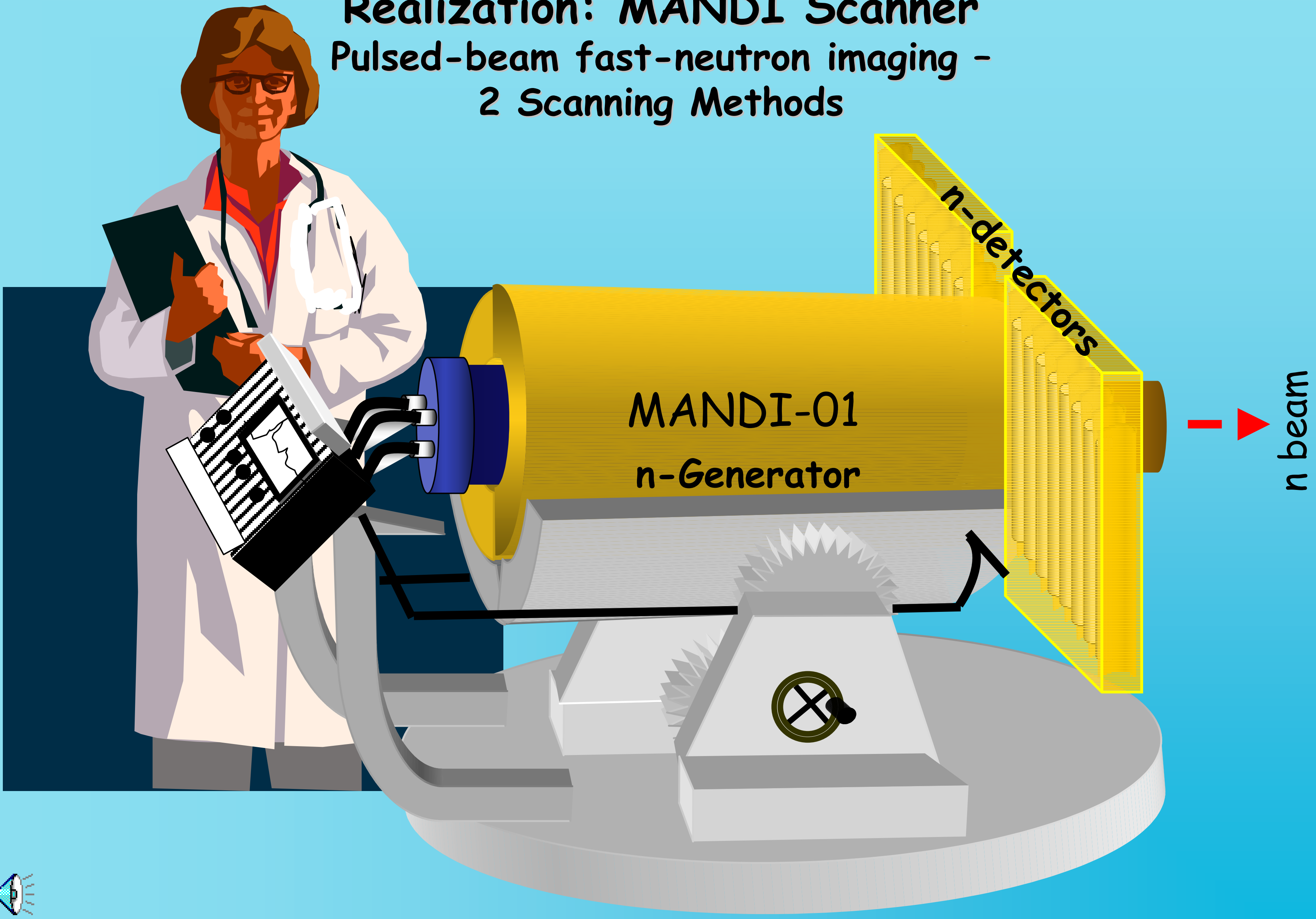
depending on the sample material

Secondary radiation induced by neutrons in the sample appear with the same frequency as the neutron pulses.

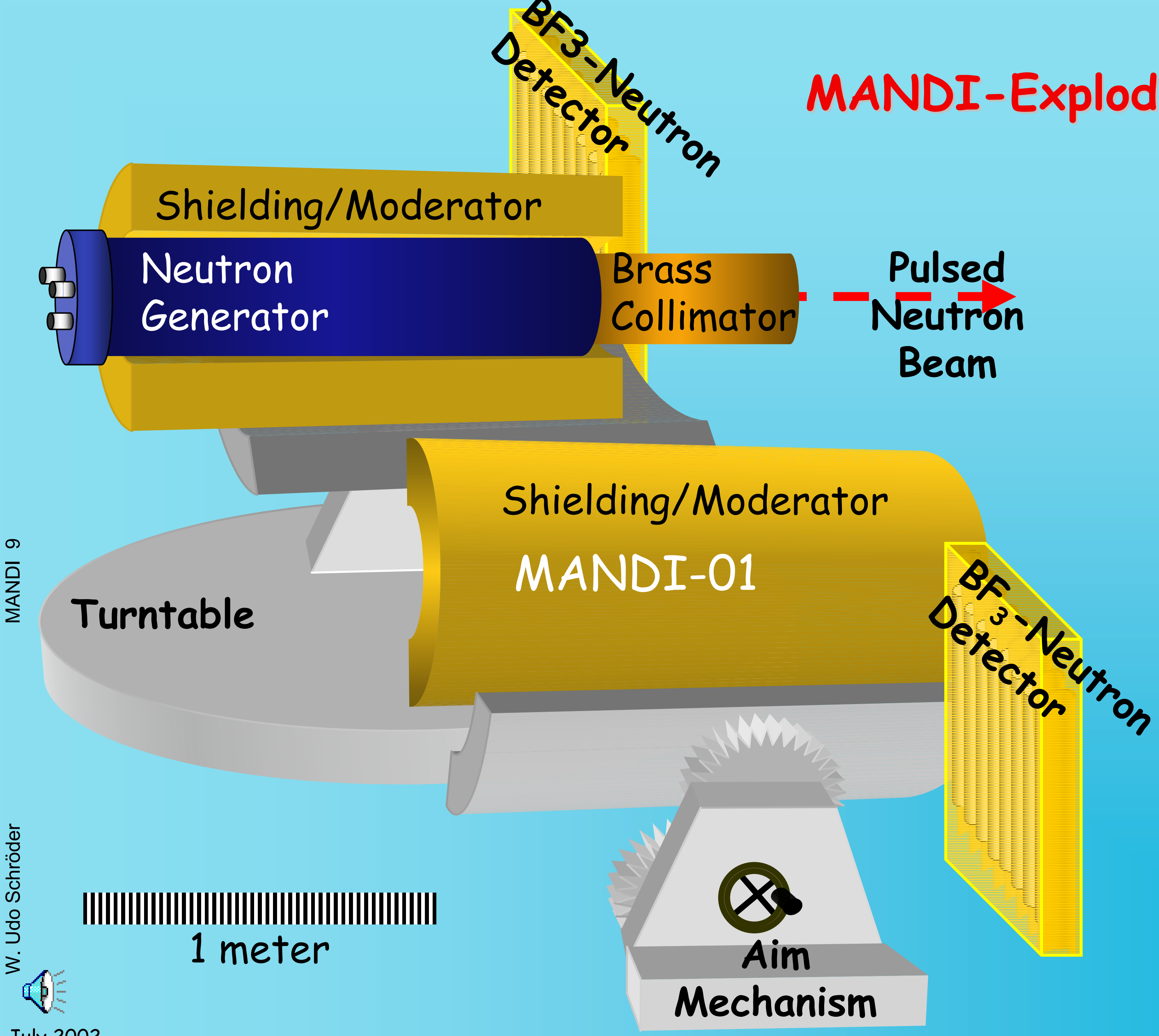
Detectors for characteristic secondary radiation improve recognition of sample material, reduce ambiguities.

Realization: MANDI Scanner

Pulsed-beam fast-neutron imaging – 2 Scanning Methods



MANDI-Exploded View



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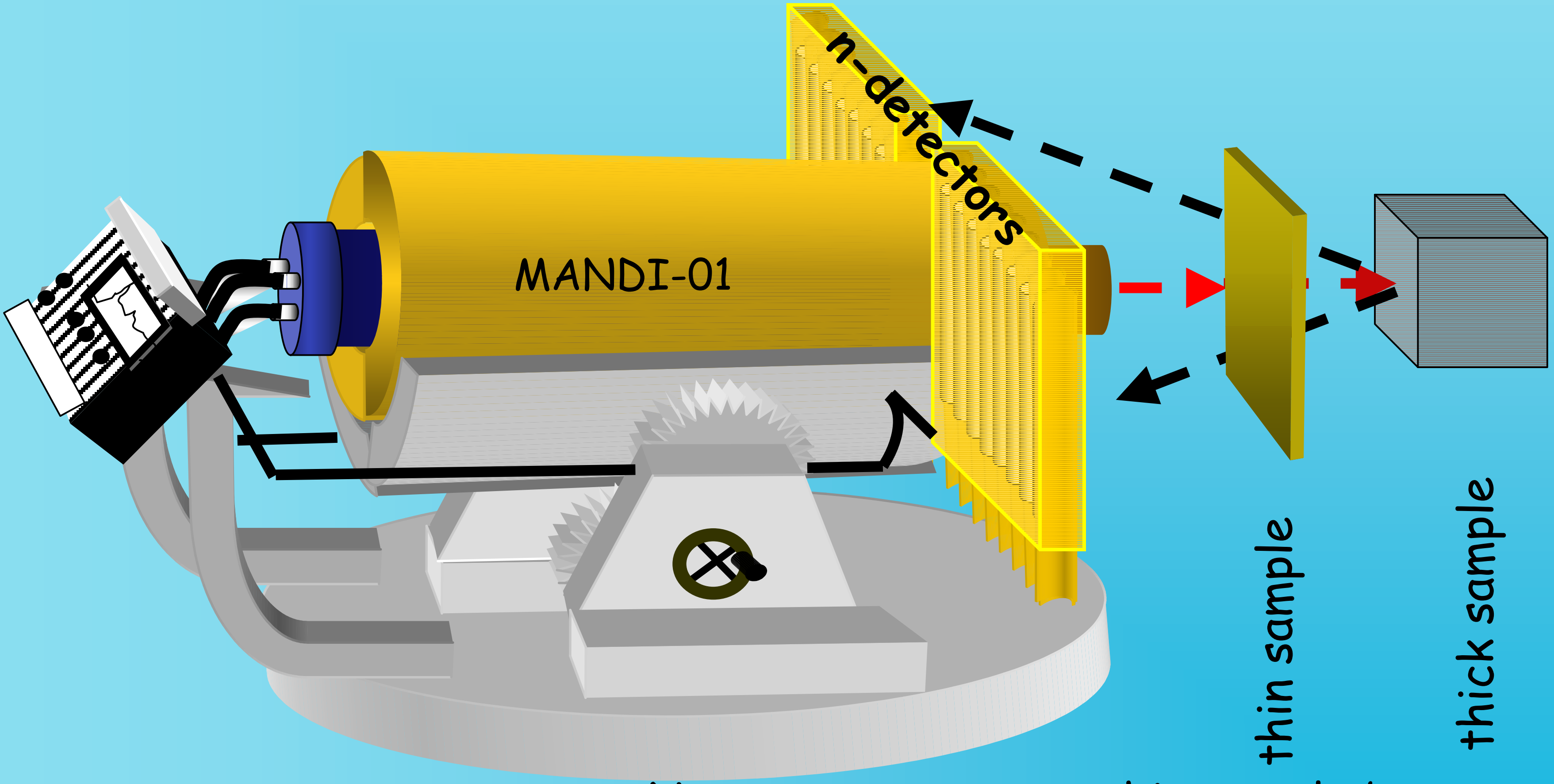
MANDI – Reflective Scanning

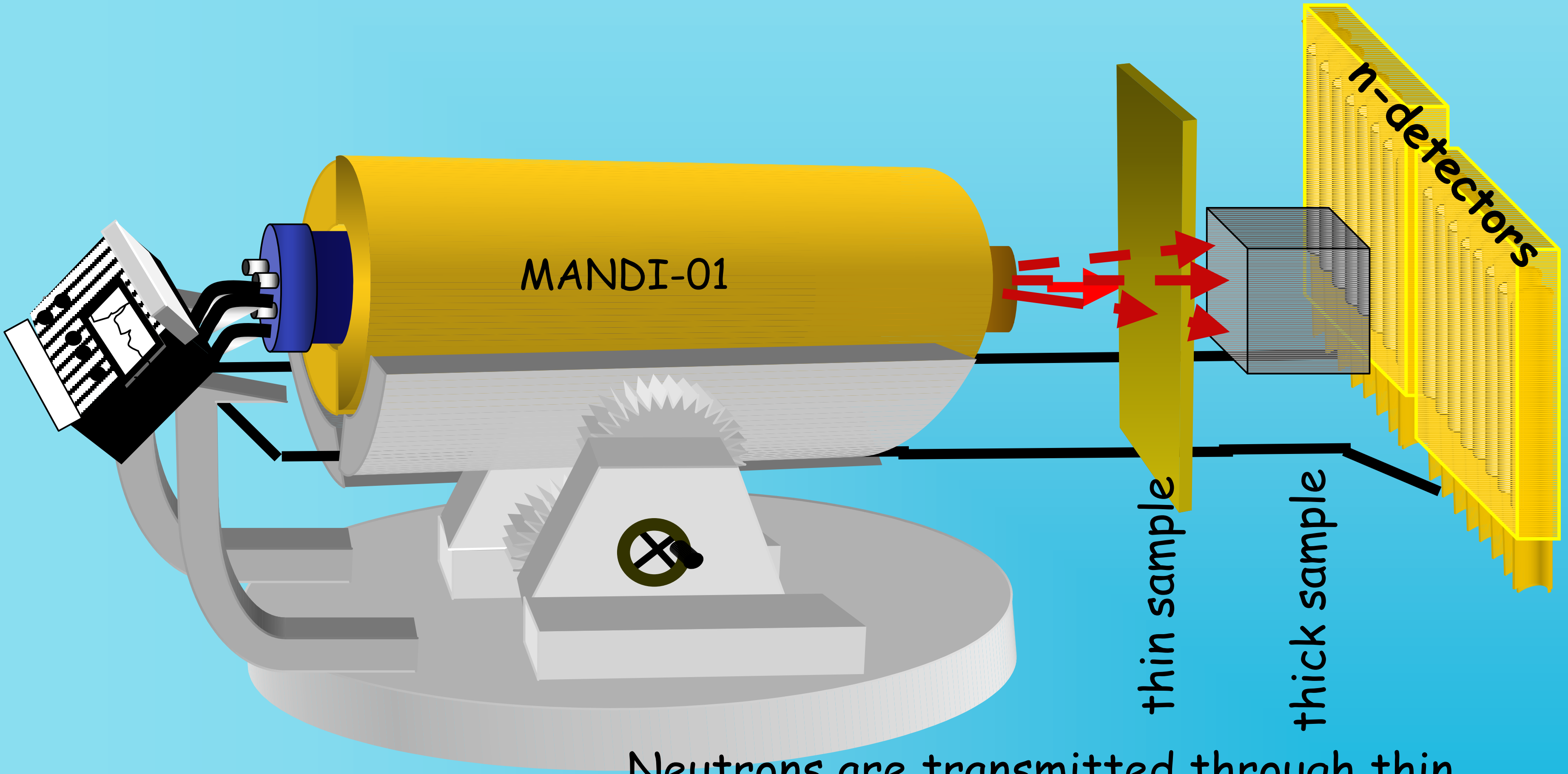
Geometry for back-scattering (reflective) neutron imaging



Neutrons penetrate thin sample but are scattered back from thick sample of heavy/dense sample materials.

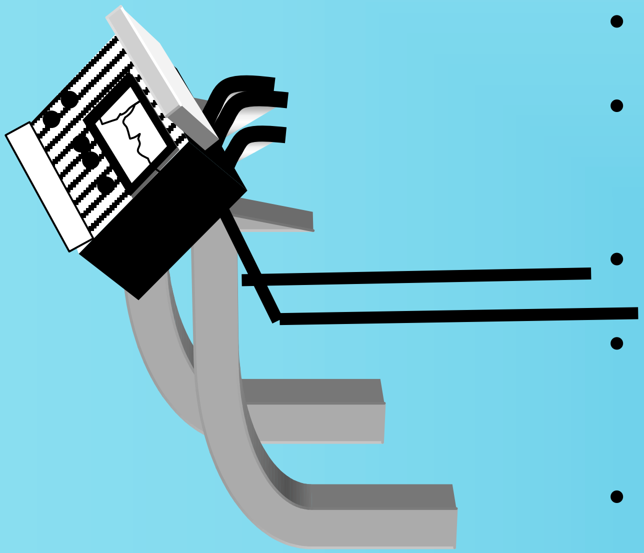
MANDI – Transmission Scanning

Geometry for transmission neutron imaging



Neutrons are transmitted through thin sheets but are absorbed by thick sample of light/medium-weight material

MANDI Scanning/Electronics



Tasks

- Control and trigger n generator
- Monitor generator operation, primary n flux
- Control detector operation
- Synchronize n detectors with pulsed n beam
- Process detector signals
- Accumulate and store data
- Accumulate and store background
- Construct and display image

Commercial Neutron Generator ING-03

Source: All-Russian Research Institute of Automatics

VNIIA

Alternative option:
$T(d,n)^4He$, E_n=15 MeV

Specs:

< $3 \cdot 10^{10}$ $D(d,n)^3He$ neutrons/s

Total yield $2 \cdot 10^{16}$ neutrons

Pulse frequency 1-100Hz

Pulse width > 0.8 μs

Power 500 W

Power supply, control unit, cables

$ 39,800


source window


rear connectors

ING-03 n-Generator

n Trigger Pulse

HV Power Input

Estimated Cost: Project Stage I

Neutron generator with power supply and control unit	$ 39,800
1 Refill Deuterium discharge tube (est.)	$ 3,000
1 Research Associate ($42k/a, 15.5% benefit)	$ 48,300
1 Student (Master of Science)	$ 21,000
Misc. Materials and shop time	$ 5,000
Overhead (On-Campus Research, 59%)	$ 43.837
Total for 1st year	**$ 160,937**
Estimate for 2nd year	**$ 121,000**

- **Project Stage I Duration** 2 years

Cost sharing by institution: laboratory/office space, shielding, subsidized shop time, infrastructure

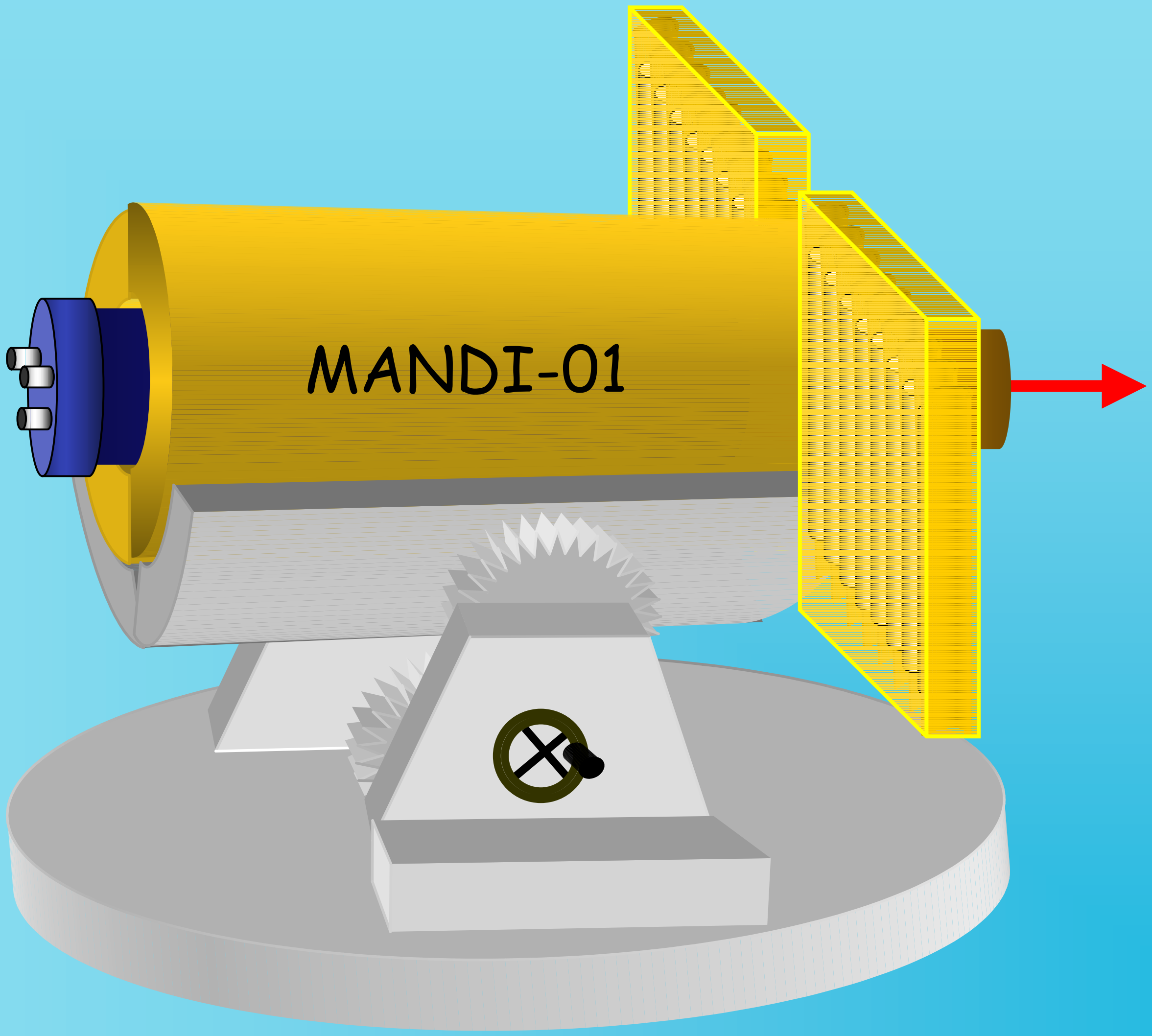
Required R&D

Stage I

- Design and construct MANDI test mounts & hardware
- Measure n energy spectra and angular distributions with and without different types of collimators.
- Design and test B-loaded plastic shielding/moderator.
- Perform extensive pulsed-beam coincidence measurements of 2.5-MeV n transport through a range of materials varying in density and spatial dimensions.
- Measure n amplification in thick fissile targets
- Assess sensitivity and quality of transmission and backscattering imaging

Stage II

- Develop computer model simulations
- Develop large-area detectors (e.g., BF_3 or BC454 B-loaded scintillation counters)
- Develop and test dedicated electronics



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