Development of a Tomographic Imaging System for HEU Components

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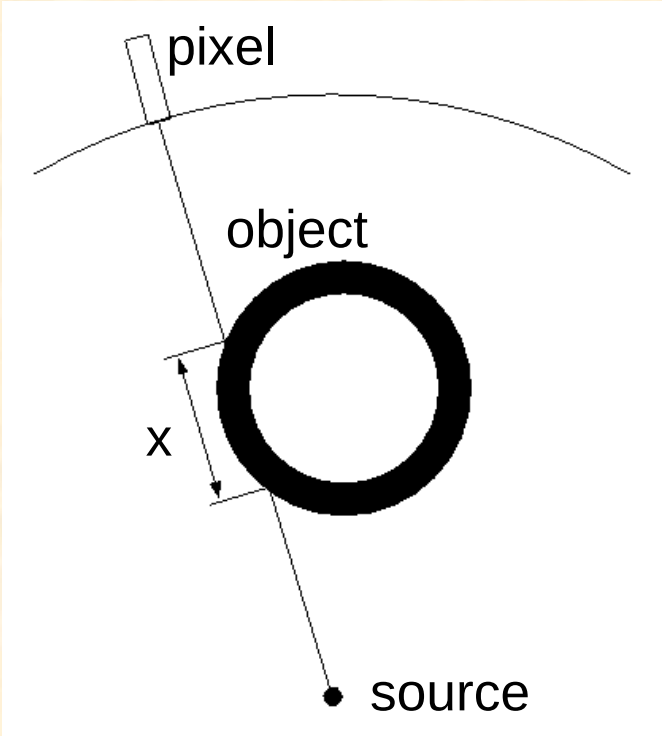
Idea of reconstruction from attenuation measurements

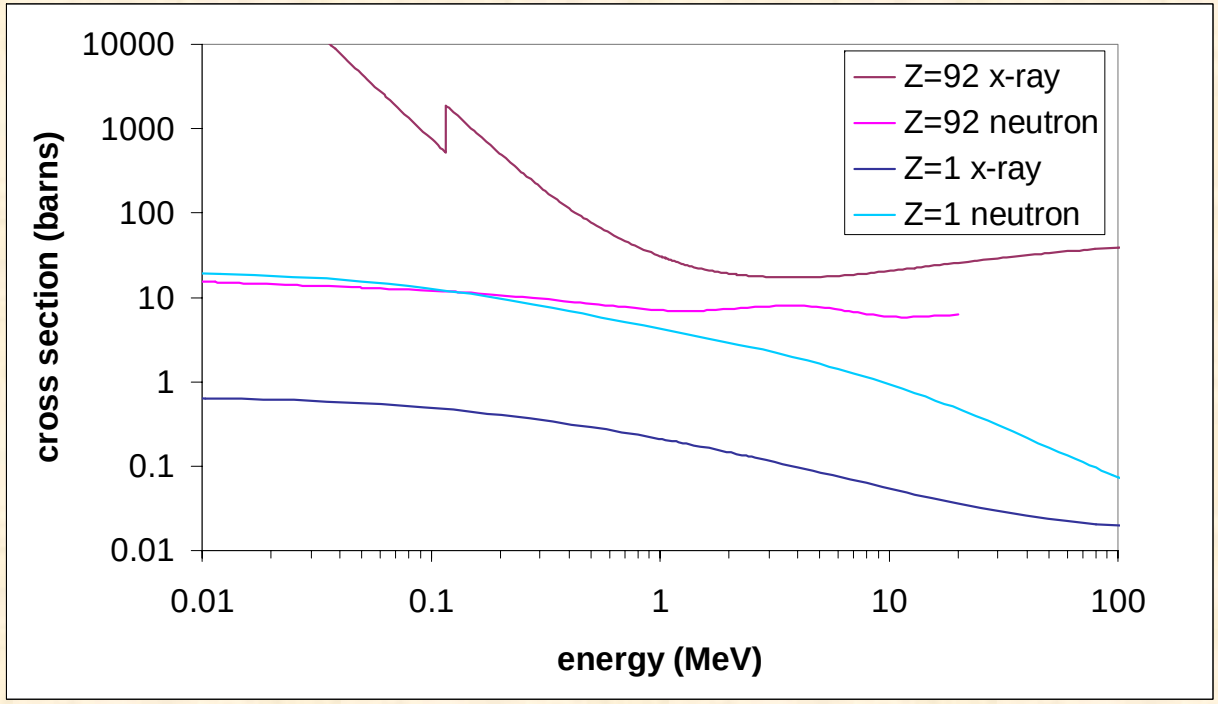


- **Number of neutrons or x-rays passing through bulk material $N=N_0\exp(-\sigma nx)$**
- **Attenuation = $\ln(N_0/N) = \sigma nx$ is a function of the physical properties (σn) and the geometry (x) of item**
- **Reconstruction is working back from attenuation measurements to define object**
- **Quality of measurement needed determined by level of reconstruction needed (determine part type or defects?)**

System and Components

- **Consists of electronically collimated DT neutron source and detectors on common gantry, NMIS processor, and analysis software**
- **Want to perform object recognition from low-resolution, few projection images + simultaneous induced reaction (fissile) measurement**

Why neutron interrogation?



- **Neutrons more penetrating for high-Z materials**
- **Neutrons more sensitive for low-Z materials**
- **Neutron-induced reactions (fission) can be used to measure functionality, not just attenuation**

Neutrons more penetrating...

- **Calculate the number of particles that need to be incident on a single pixel to get 100 counts through different thicknesses of U**

U thickness	14 MeV neutrons	4 MeV x-rays	500 keV x-rays
3 cm	230	1200	6×10^{6}
10 cm	1700	3.9×10^{5}	9×10^{17}

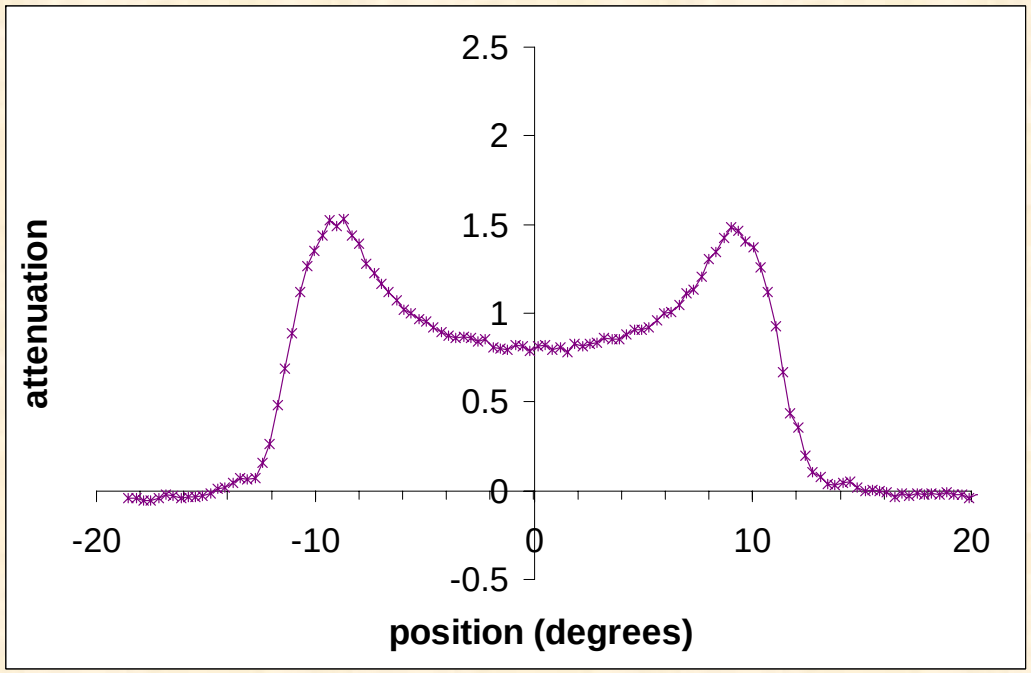
- **Neutrons provide most efficient use of source radiation**

Why DT neutrons?

- **D-T reaction cross section peaks at low energy (100 keV D) allows small package**
- **Detection of alpha from D-T reaction gives direction of outgoing neutron to "electronically collimate" neutron beam**
- **Based on reaction, not decay, so can be turned off**
- **Electronic collimation permits wide cone beam for efficient use of neutron flux**

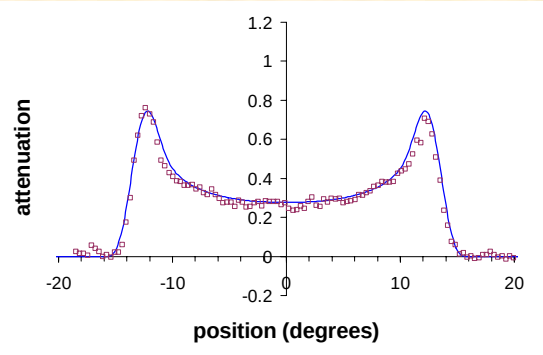
Laboratory measurements

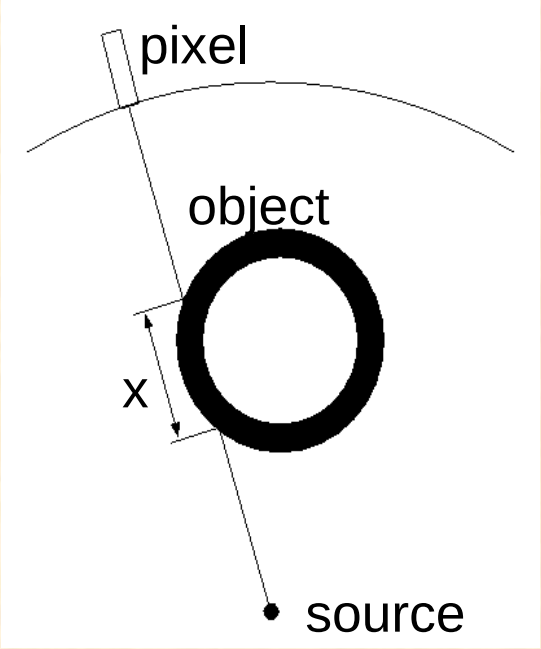
- **One slice through a DU casting**
- **Recall attenuation proportional to the "amount of stuff"**



Interpretation

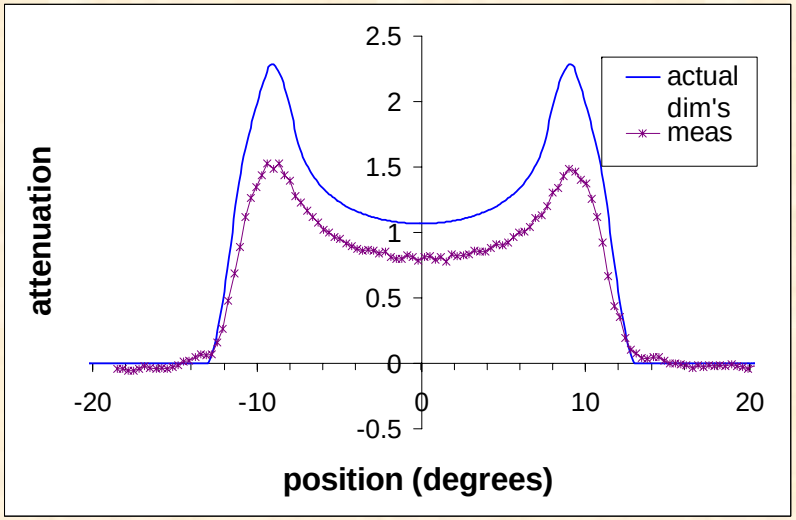
- **A general reconstruction of each volume element requires many projections of high-resolution radiographs**
- **In the case of a few well-defined objects, many fewer variables than volume elements (e.g. pipe has length, OD, ID, material, position, and orientation)**
- **For a given value of these attributes, can analytically calculate the attenuation of an object**
- **By varying attributes, can calculate the attributes that best fit the measurement**



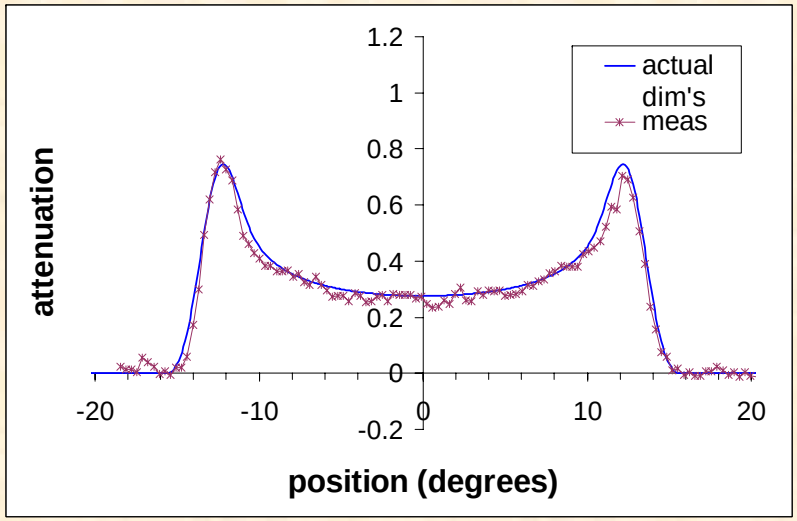


How well does this work?

DU casting



Steel pipe



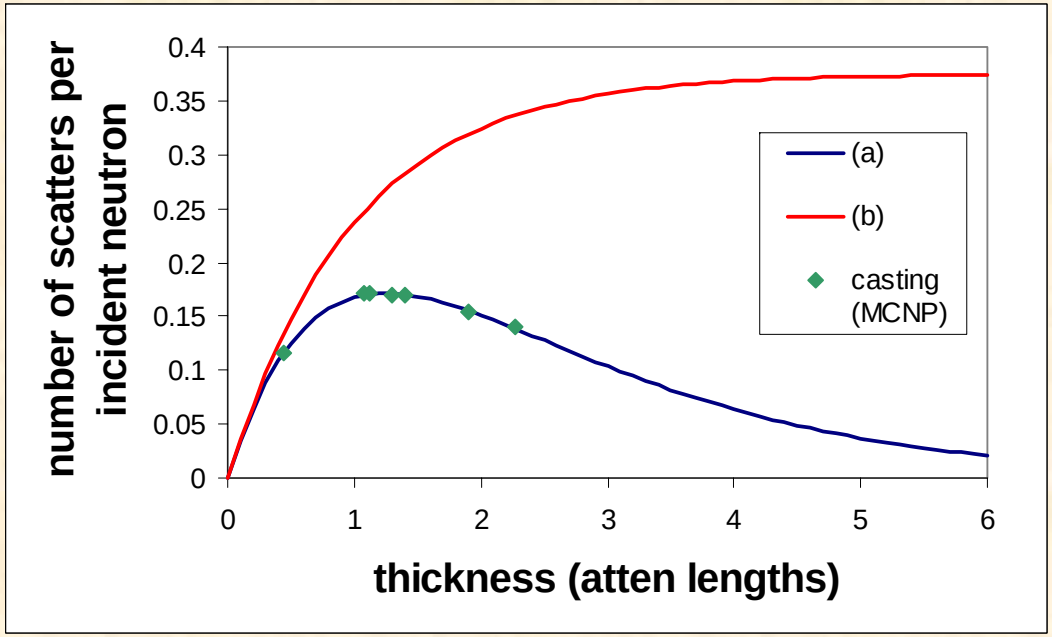
- **Measurements agree with attenuation for thin objects**
- **Measurements disagree for thick objects**
- **Why? Scattering.**

Scattering

- **For thick objects, almost all neutrons have interacted, mostly by scattering**
- **If a small number of neutrons scatter in such a way that they are still detected, this will make the observed attenuation less**
- **Size of source (D-beam spot size on generator T target) means neutron direction only approximately determined- some scattered neutrons indistinguishable from direct neutrons**
- **Cannot exclude in-scattered neutrons from measurement, need to include in analysis provided it can be calculated sufficiently quickly**

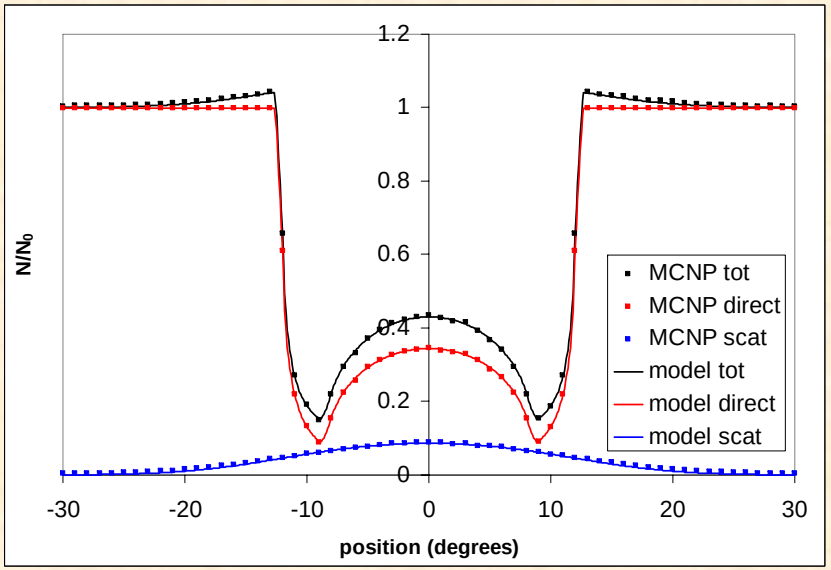
Scattering (cont.)

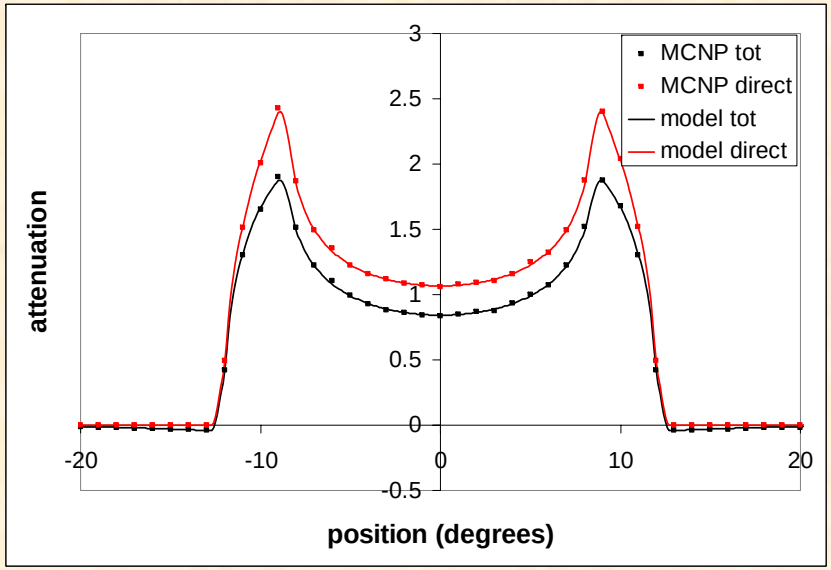
- **The number of neutron scatters that still reach a detector can be calculated analytically if (a) scattered path is about same length as direct path or (b) neutron exits material as soon as it scatters**



- **Assumption (a) describes a typical geometry well**

Comparison of analytic scattering to Monte-Carlo for DU casting





- **Analytic scattering suitable for iterative minimization routine (fast)**
- **Agrees with MC-generated (MCNP) scattering in form and magnitude**

Conclusions

- **Fast neutrons sufficiently penetrating to measure geometry of thick, high-Z objects while still sensitive to low-Z constituents**
- **Present finite source size (~1cm) limits achievable resolution, requires interpretation of data to include scattering**
- **Scattering description will allow uniform interpretation of the same object regardless of proximity to other material (e.g. in or out of barrel, near something highly attenuating)**
- **Scattering description can be generalized to include other sources**