Optimization of Neutron Activation of Carbon at the NIF

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Goals

- To determine the lower limit on the tertiary yield measurement for the carbon activation diagnostic.
- Examine the geometric and attenuation losses in the activation diagnostic at the NIF chamber

Approach

- A finite element calculation was performed to set the lower limit on the sensitivity of the activation diagnostic
- A study of the published $^{12}C(n,2n)$ cross sections in the 20 to 30 MeV energy range
- A verification of MCNPX calculations

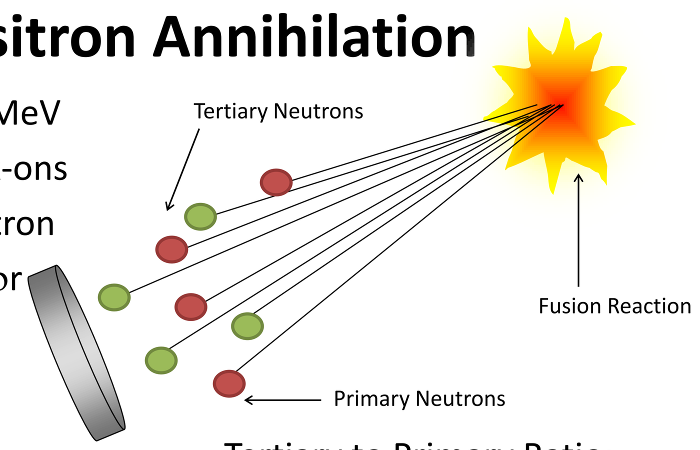
Carbon Activation and Positron Annihilation

$D_{fuel} + T_{fuel} \rightarrow \alpha + n_{14.1\,Me}$ All primary neutrons are 14.1 MeV

$n_{14.1\,MeV} + D_{fuel} \rightarrow n^{*} + D_{ko}$ Producing 0 – 12.5 MeV knock-ons

$D_{ko} + T_{fuel} \rightarrow \alpha + n^{**}$ Producing 12 - 30 MeV tertiary neutron

The number of tertiary neutrons is related to $(\rho r)^2$ or ρr parameter



$$D_{ko} + T_{fuel} \rightarrow \alpha + n^{**}$$

$$n^{**} + {}^{12}C \rightarrow 2n + {}^{11}C$$

Tertiary to Primary Ratio:
1 tertiary per 1,000,000 primary's

$$^{11}C \rightarrow {}^{11}B + e^{+}$$

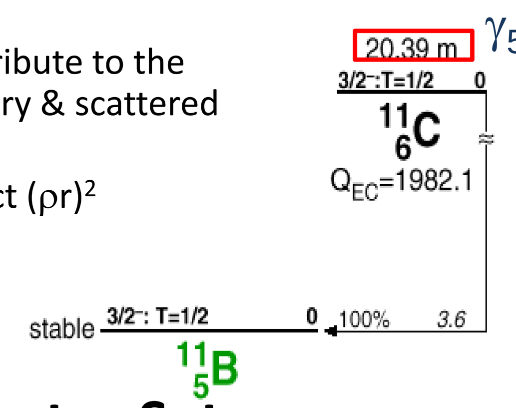
$$e^{+} \rightarrow 2\gamma_{511KeV}$$

Carbon is ideal for the detection of primary and secondary neutrons for several reasons:

•Only tertiary neutrons from the burn contribute to the 12C(n,2n)11C reaction (insensitive to primary & scattered neutrons)

• Sensitive to the fuel density-radius product $(\rho r)^2$

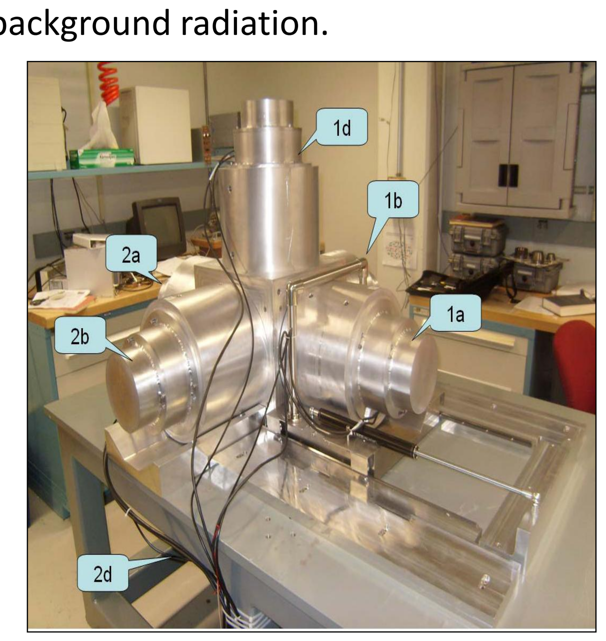
•Robust, inexpensive, reusable and reliable



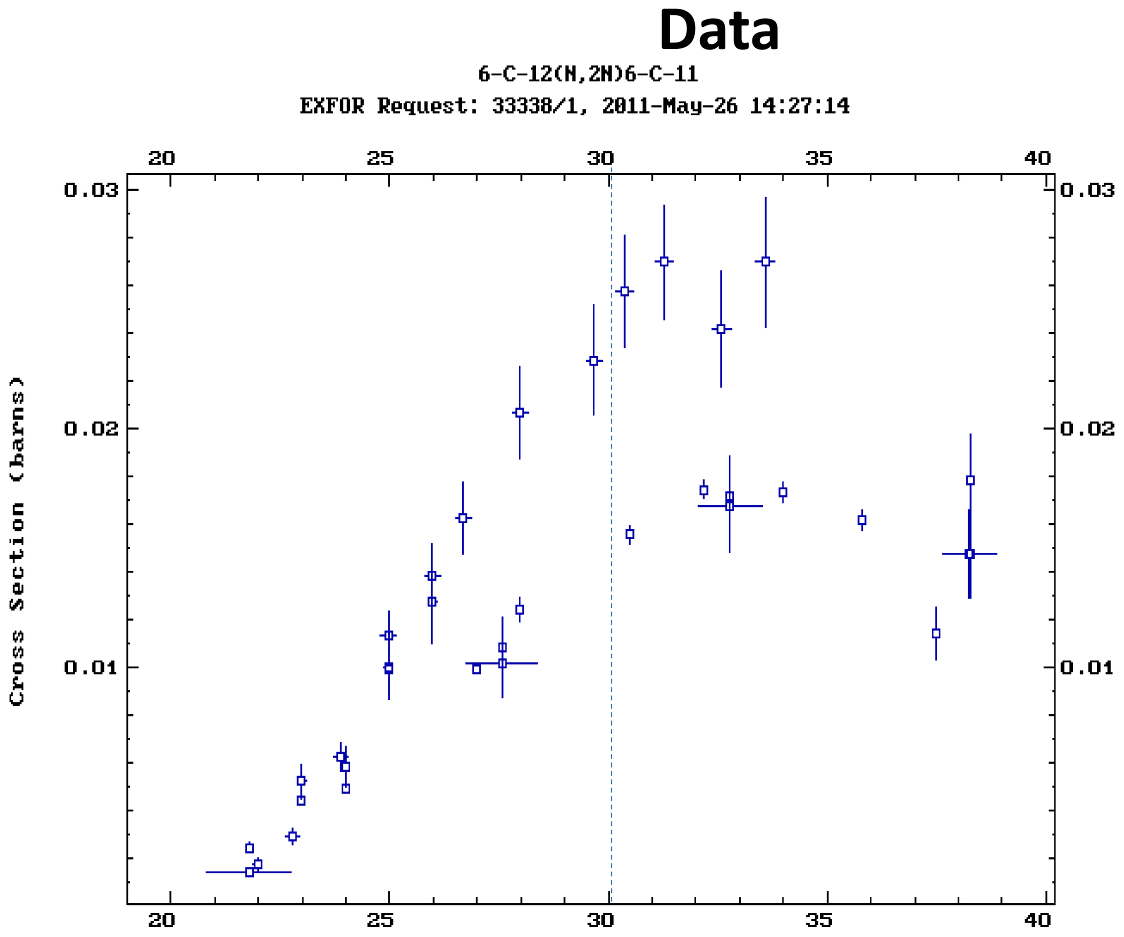
LLE Detector Setup

The six NaI detectors are arranged on Cartesian axis. The detectors are shielded with lead to reduce ambient background radiation.

Detector setup at LLE where detectors are kept within a lead shield. During acquisition, a carbon sample is placed in the center of the array.

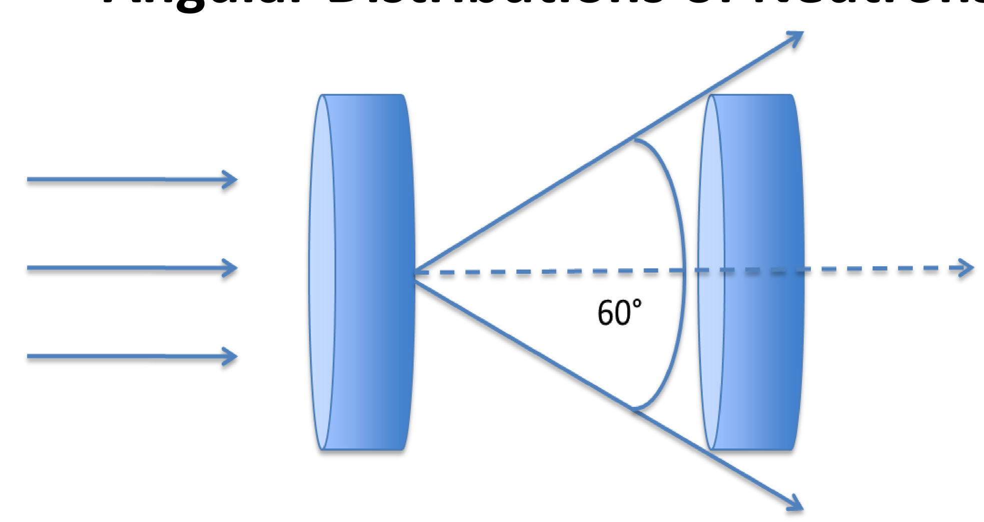


$^{12}C[n,2n]^{11}C$ Cross Section Data

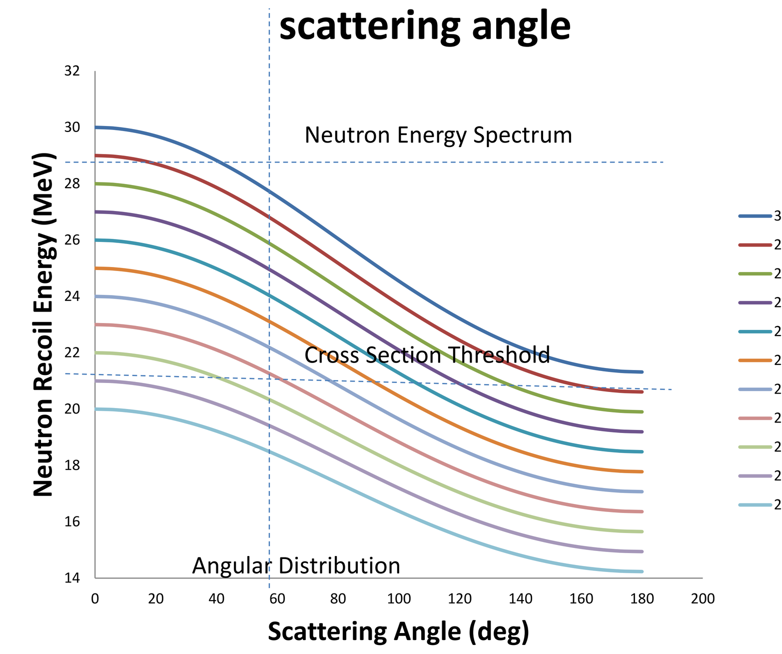


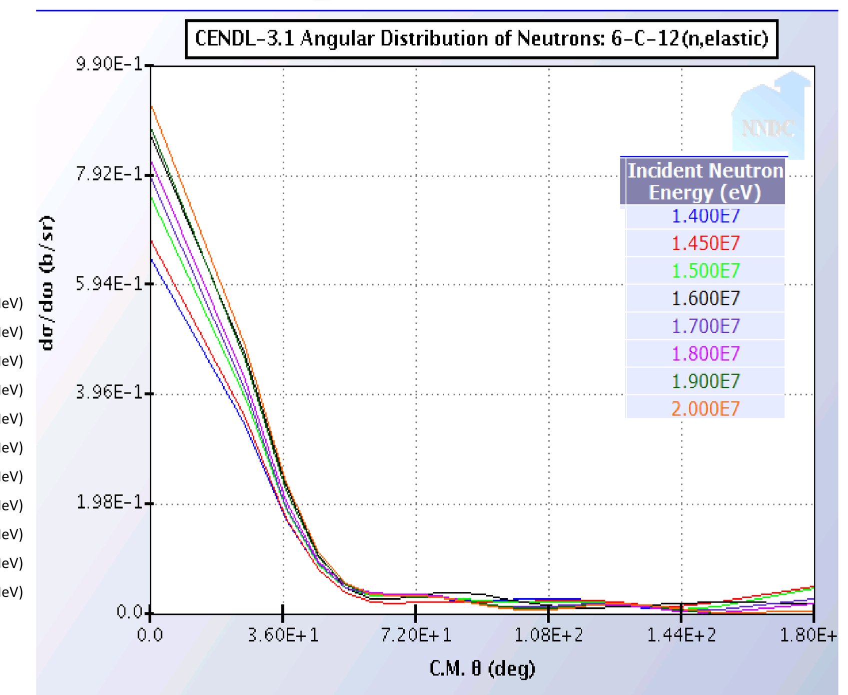
Due to carbon's 20.3 MeV reaction threshold, it is insensitive to 14.7 MeV primary neutrons which are measured by other means and allows for an unambiguous determination of the tertiary to primary ratio.

Angular Distributions of Neutrons



$^{12}C[n,n]^{12}C$ recoil neutron energy vs scattering angle

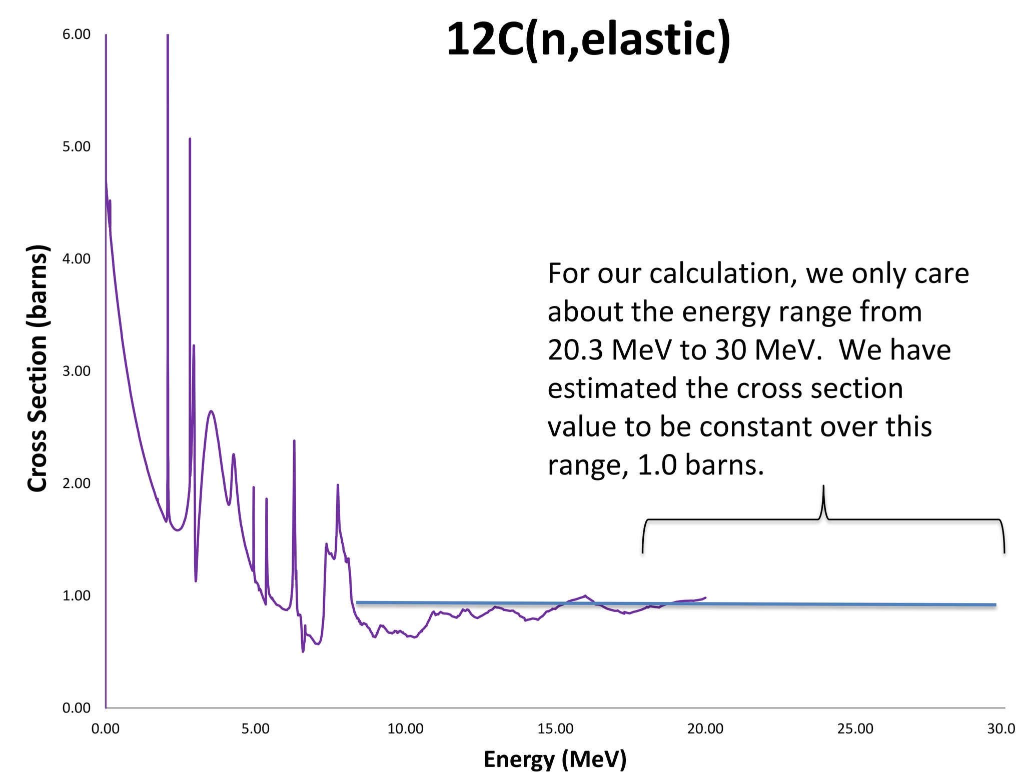




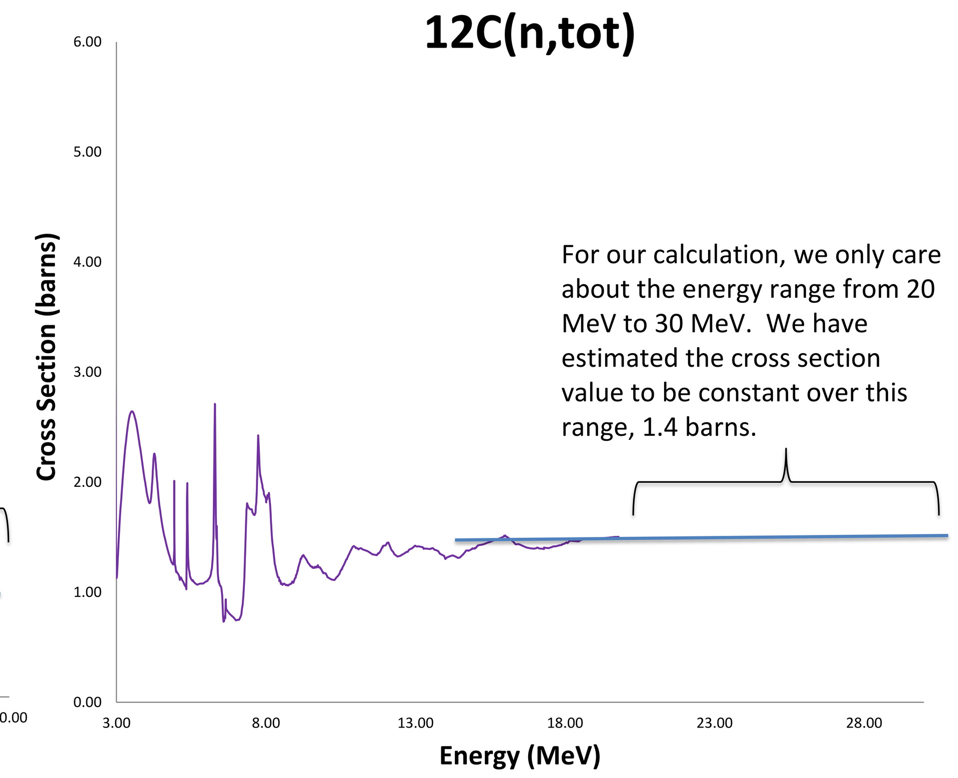
- The angular distributions of elastically scattered neutrons shows that it is unlikely for neutrons to be scattered at angles greater than 60 degrees.
- Neutrons with an energy less than 20.3 MeV do not play a role in the activation of Carbon.
- Very few neutrons are produced greater than 27 MeV in an ICF reaction.

Other Related Cross Section Data

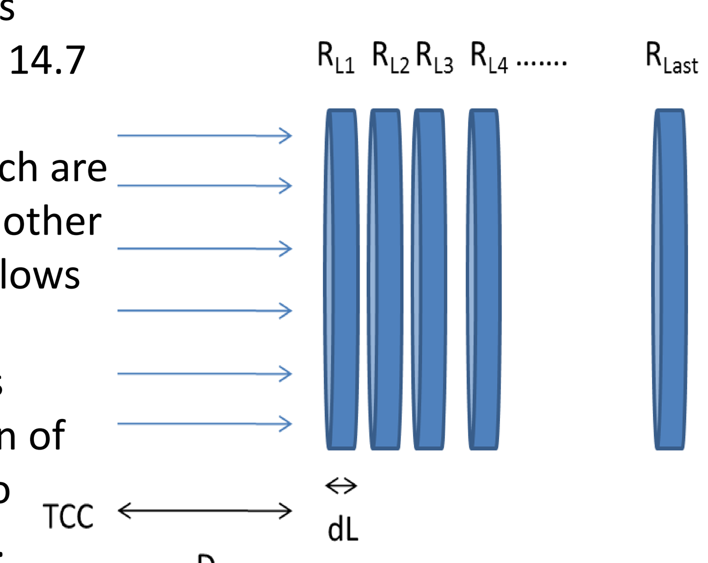
12C(n,elastic)



12C(n,tot)

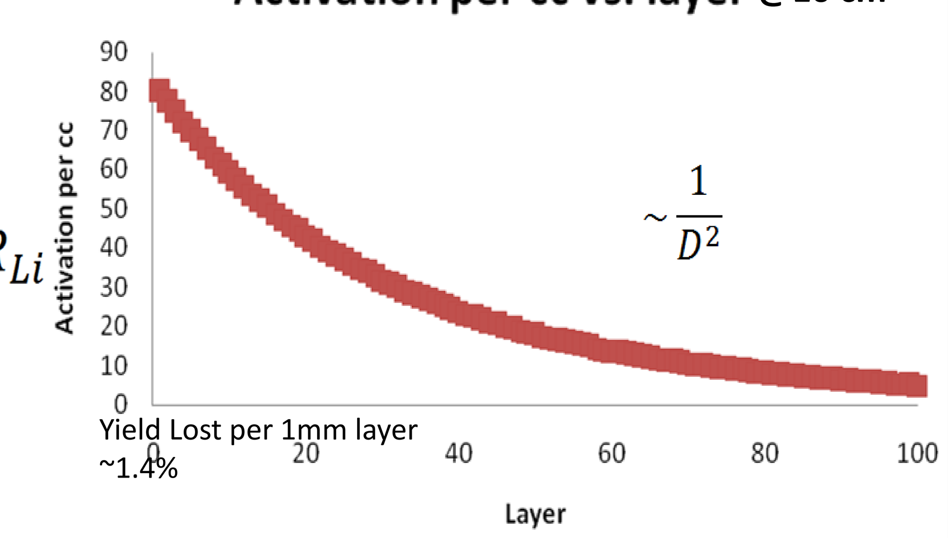


Finite Element Calculation



$$R_{Total} = \sum_{i=1}^{n_1} R_{Li}$$

Activation per cc vs. layer @10 cm



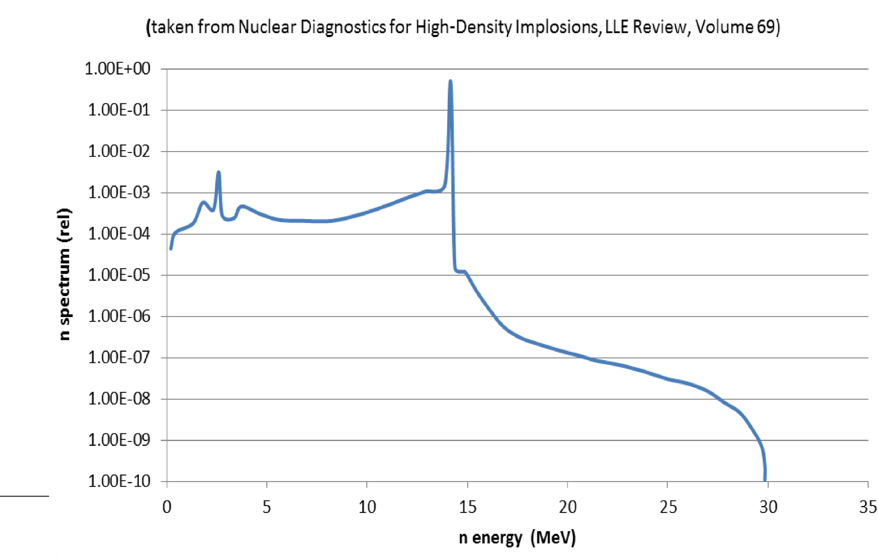
The purpose of the finite element calculation was to determine activation for a stack of thin foils which approximated a solid right cylinder. The graph on the upper right shows that at 10 cm from TCC the activation is influenced by geometric loss.

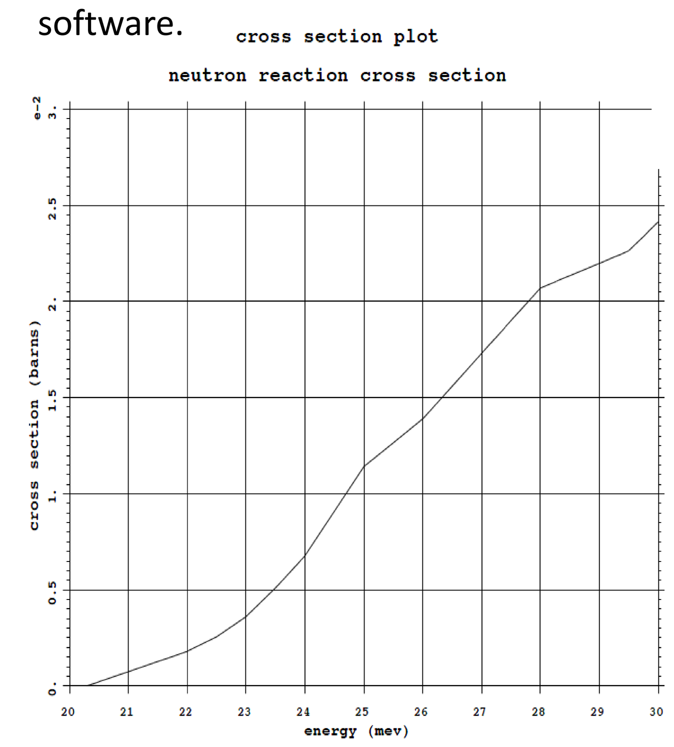
MCNPX Analysis

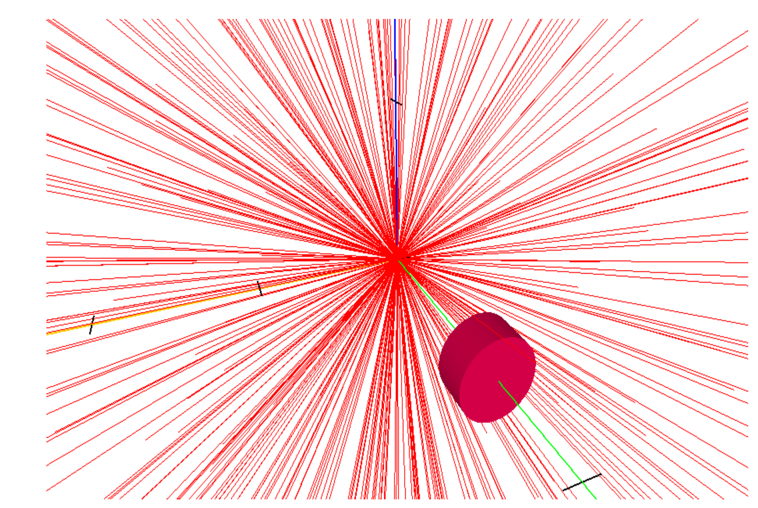
The following neutron energy spectrum was used in the MCNPX input file. The graph below is the cross section file used, which is library 6000.66c for natural carbon, but more importantly includes data from 20.3 MeV to 30 MeV. The input geometry file and the PTRAC data were displayed using iViPP software.

ICF neutron spectrum

(taken from Nuclear Diagnostics for High-Density Implosions, LLE Review, Volume 69)

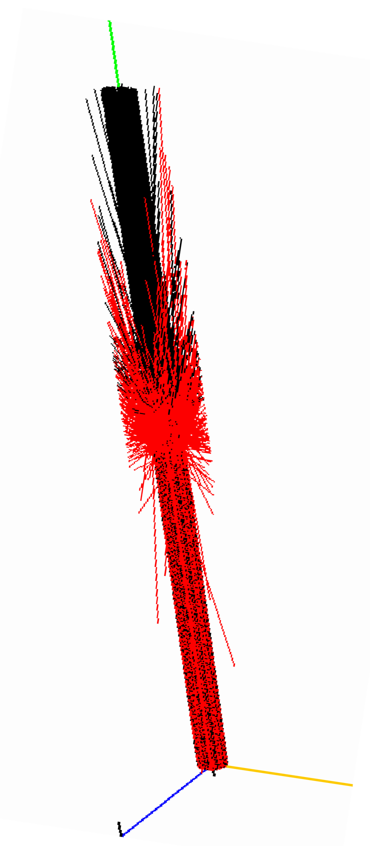






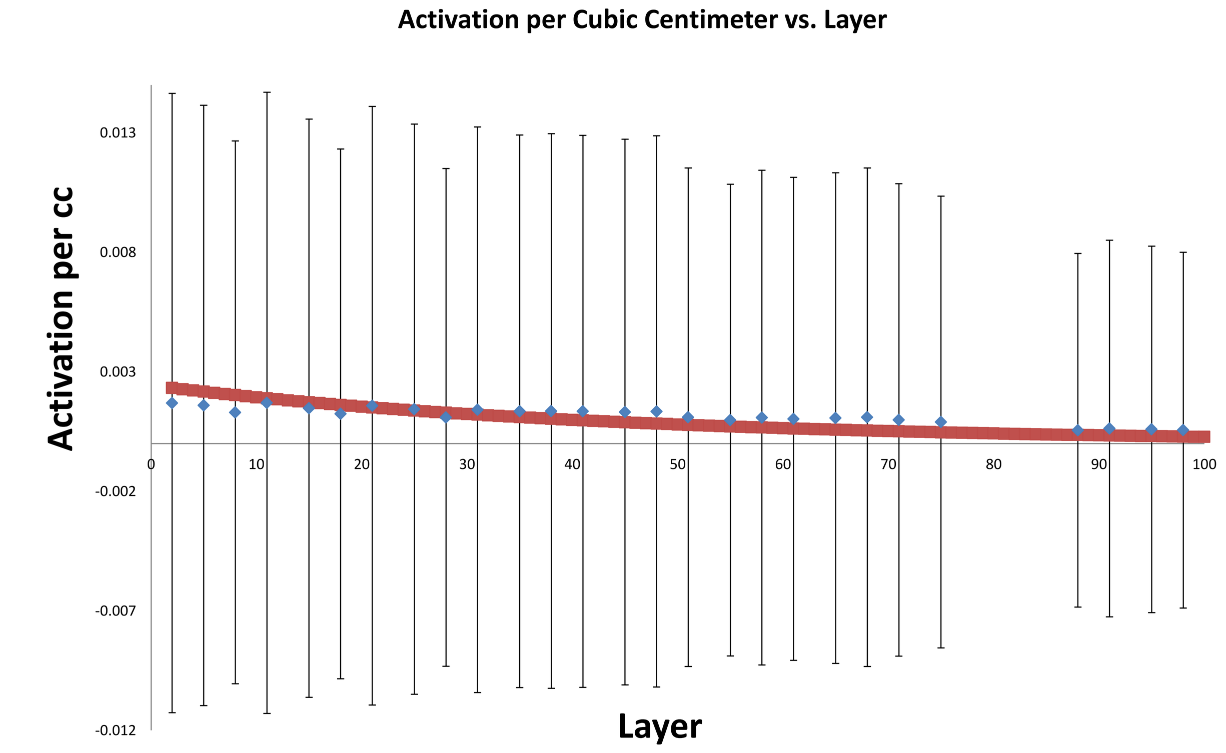
MCNPX and iViPP Analysis

Using the visualization program iViPP, which is capable of displaying neutron trajectories using the MCNP PTRAC files, we manually determined the activation for 1 mm slices of graphite, using disk selectors and determining the flux of neutrons through successive planes. In the image to the right, we have placed a disk selector in the center of the graphite cylinder. The black tracks are the neutrons passing through the plane of the graphite, while the red are the tracks of the neutrons which have scattered from the graphite.



Conclusion

Activation per Cubic Centimeter vs. Layer



Using the fluences from iViPP, we were able to calculate the activation of the graphite from the MCNPX data and compare it to the calculated finite element activation.

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