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AFCI Gas Production Measurements

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Some words of explanation

- **“Gas production” = hydrogen and helium production = (n,xp), (n,xd), (n,xt), (n,x3He) and (n,xalpha)**
- **These reactions are part of the “source term” for radiation damage – swelling, blistering, changes in ductility, …**
- **The other part of the source term is “pka” = primary knock-on atoms, that is, the displacement of atoms in a material.**
  - **PKA is usually calculated from total reaction cross section**
- **Accuracy of 15 to 20% in these cross sections is usually considered adequate - -** [maybe we should aim for better?]

We are measuring gas production (hydrogen and helium) in neutron reactions with structural and other materials for the Advanced Fuel Cycle Initiative.

- **To provide data for AFCI – “Gas Production” by neutrons on structural and other materials – e.g. Fe, Cr, Ni, Zr, Ta, W etc.**
  - **The cross sections are “source terms” for assessing radiation damage of materials**
  - **Gas production is an important component of radiation damage in materials irradiated to high fluences in advanced fuel concepts.**

- **To test nuclear reaction models for basic physics so that models can be used with greater confidence**
  - **Pre-equilibrium particle emission (e.g. C. Kalbach-Walker)**
  - **Nuclear level densities**

Materials of current interest span a large range in nuclear charge and mass

- Fe
- Cr
- Zr
- Mo
- Ta

Maybe also

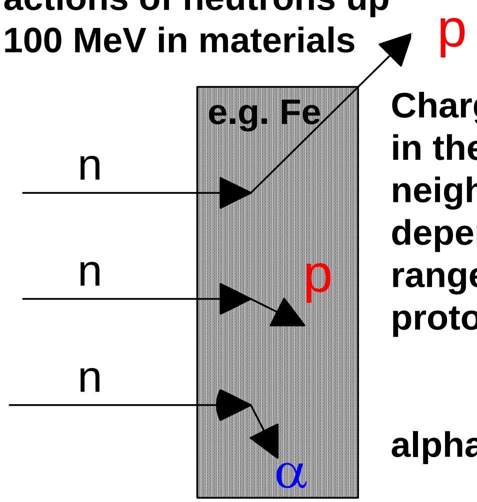
- O
- N
- …

- Different experimental challenges
  - different lower limits to charged particle energies
  - different cross sections (high Z, lower σ)
- Different emphasis on reaction mechanisms
  - Higher Z -> Pre-equilibrium more important relative to compound evaporation

We measure gas production (hydrogen and helium) in thin samples

Usual application – thick materials

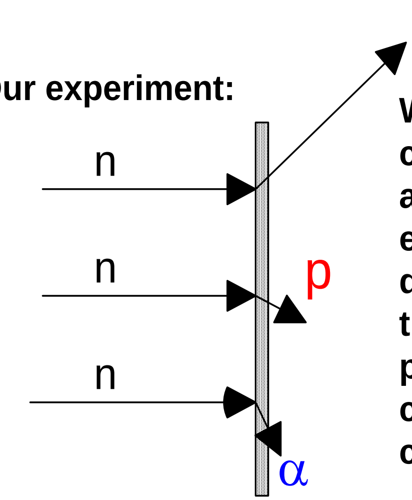
Interactions of neutrons up to 100 MeV in materials



Charged particles stop in the material or neighboring materials, depending on the range:
protons -- mm to several cm-> hydrogen
alphas - mm -> helium

Our experiment

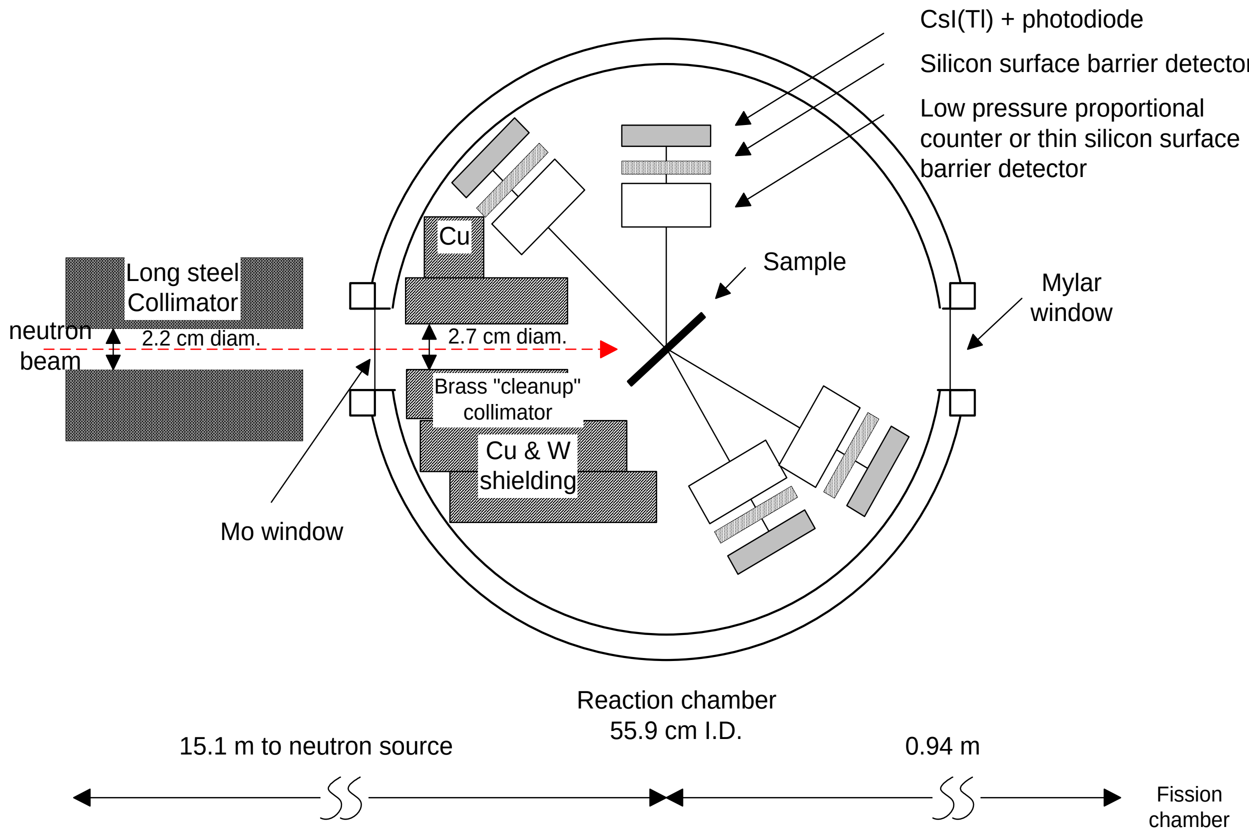
Our experiment:



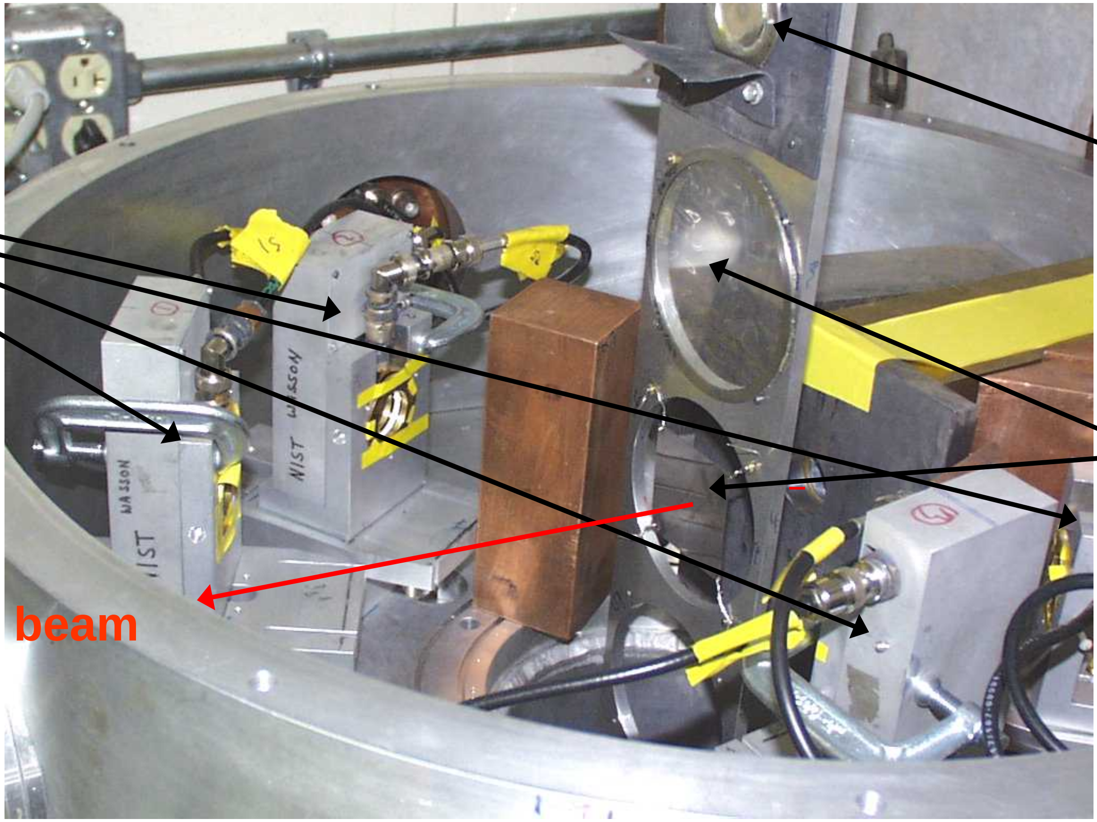
thin foil - to let particles escape with little energy loss

We detect outgoing charged particles and measure their energy and angular distributions -- then H and He production can be calculated with confidence.

Charged particles emitted in the reactions are identified by ΔE detectors and their energies are determined by stopping detectors of silicon or CsI(Tl)



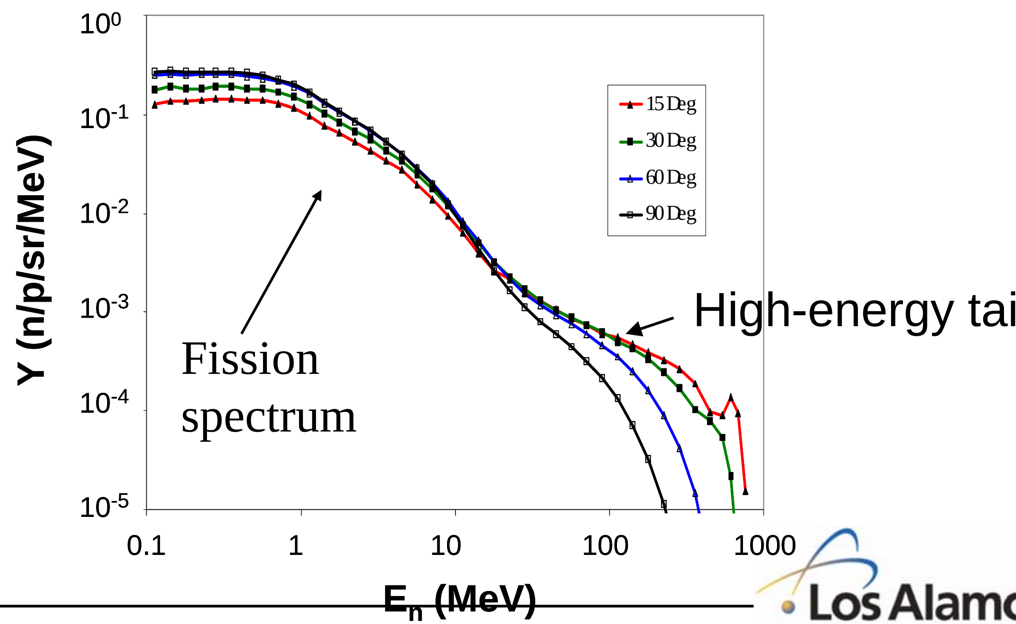
Samples and detector telescope are positioned in a reaction chamber.



Our energy range is from threshold (~ a few MeV) to 100 MeV

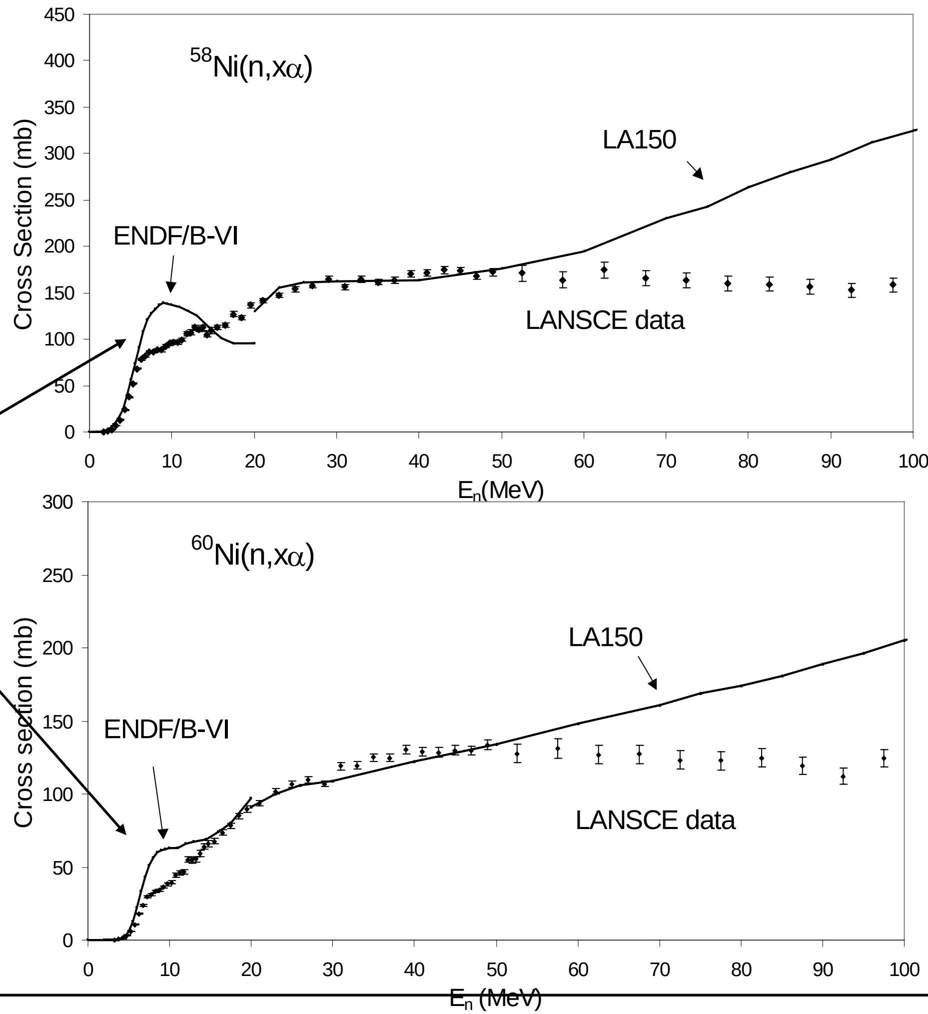
- **Energy range can be studied in one experiment**
- **Covers reactor energies – up to ~ 10 MeV**
- **Covers both the lower and higher neutron energies of interest to accelerator-produced neutron sources – If they are used for radiation damage studies for fission reactors, is a correction necessary for the high energy neutrons?**

For example, neutron spectrum at WNR/LANSCE



Data for helium production from neutrons on ^{58}Ni and ^{60}Ni showed significant deviations from evaluated data libraries

Region of reactor interest



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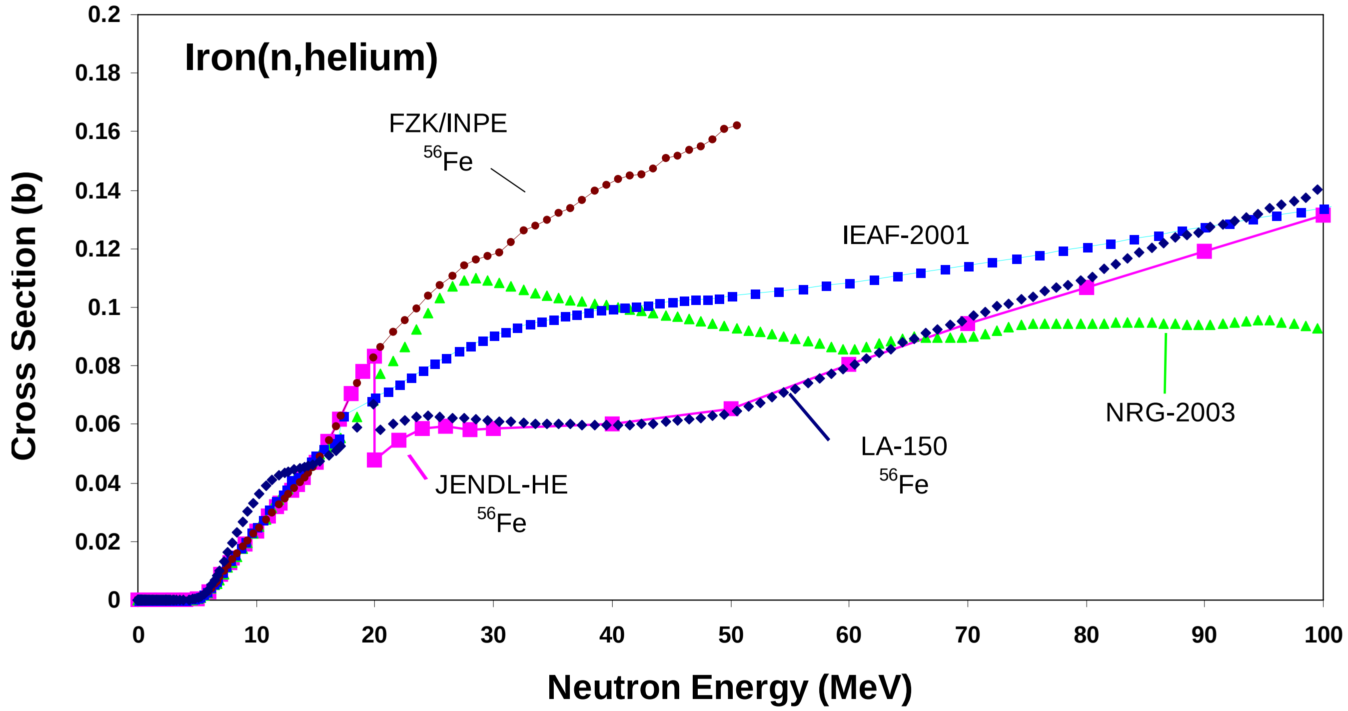
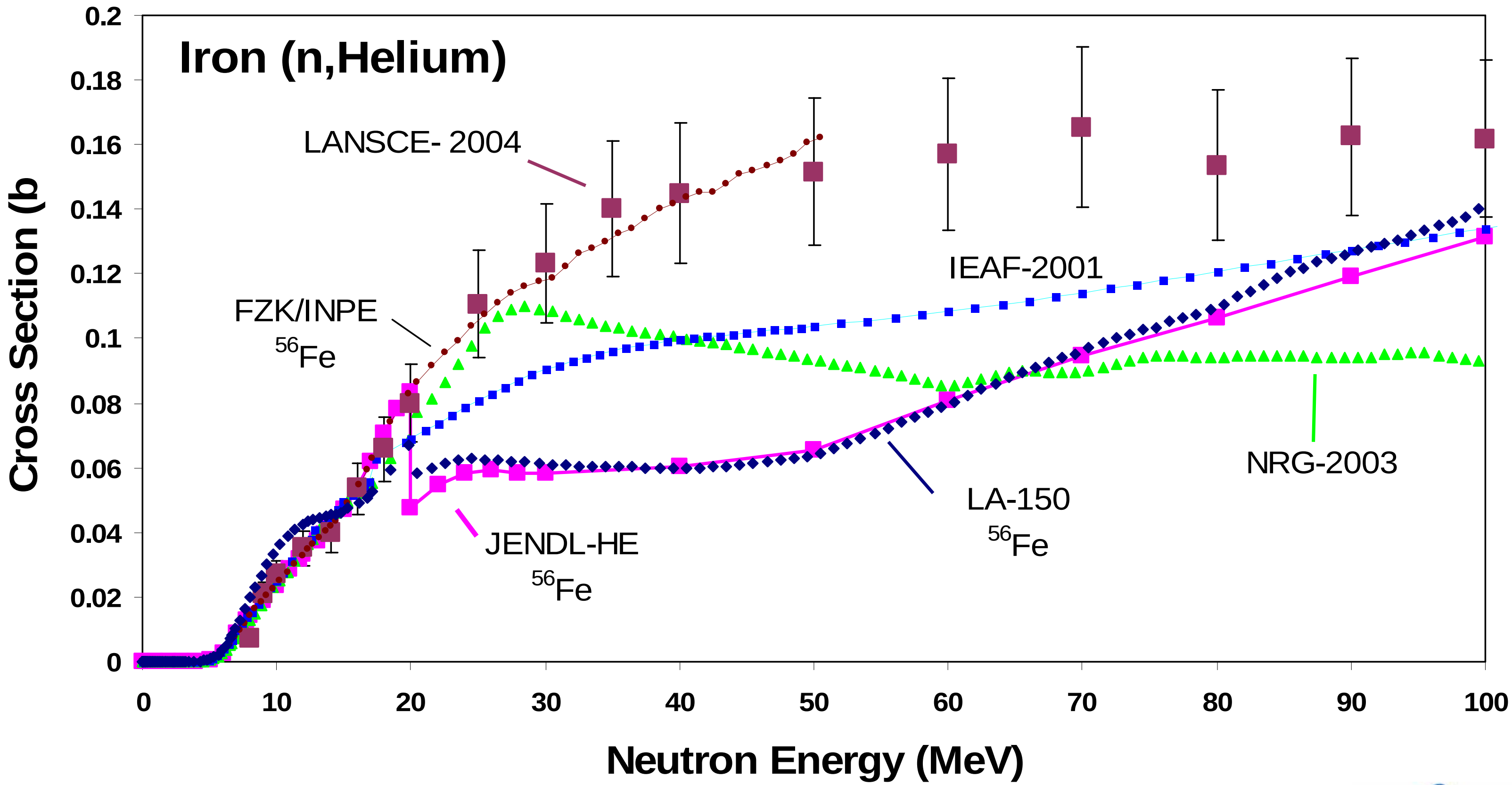
For iron, different evaluations give very different values for helium production, especially above 20 MeV



For tantalum, no evaluations for this energy range

New data for helium production from neutrons on iron allow selection between evaluated libraries



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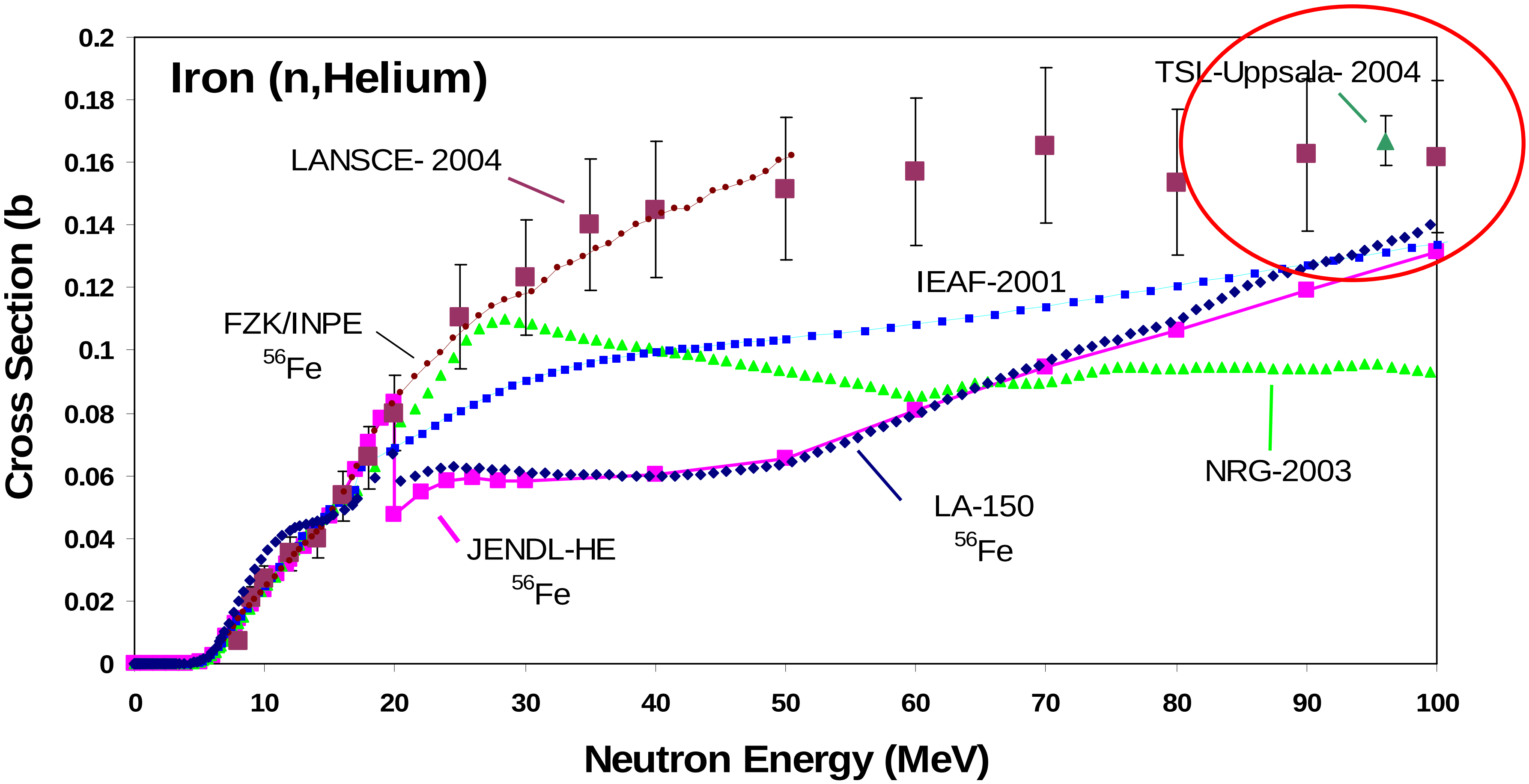
Measurement at 96 MeV from Uppsala confirms our results



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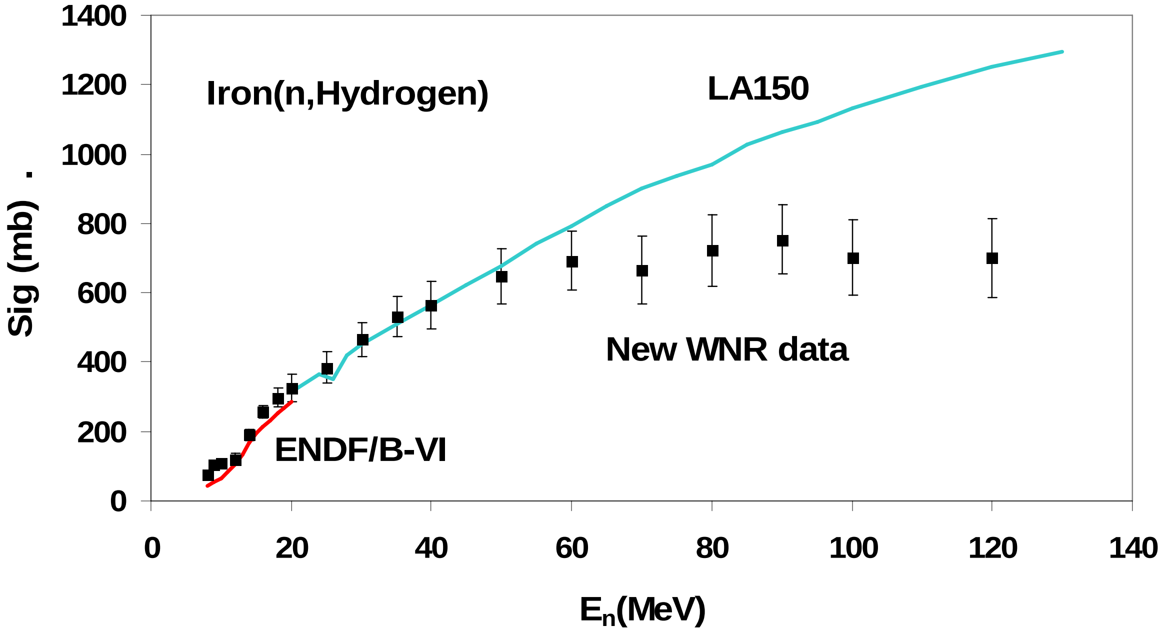
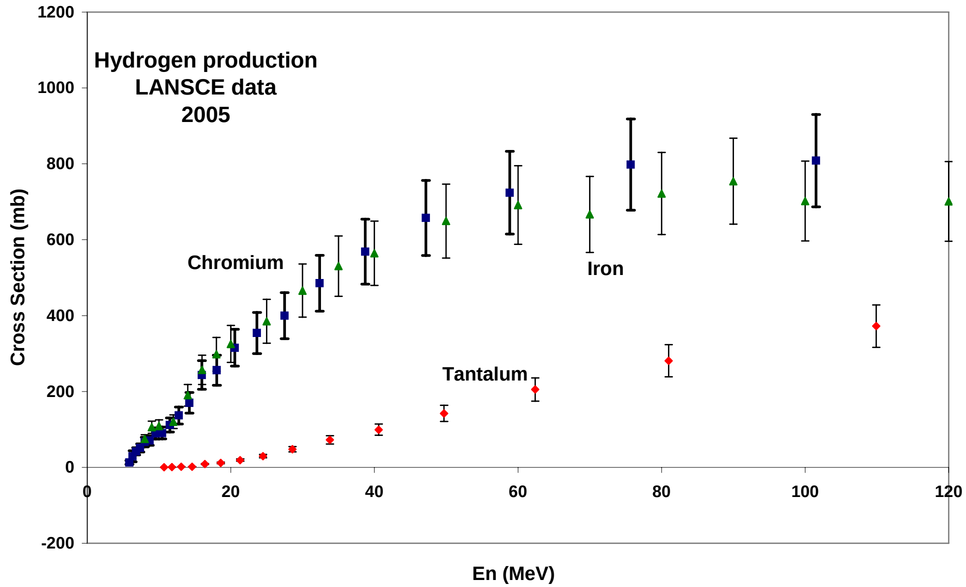
Results for hydrogen production on iron confirmed LA150 evaluation up to 50 MeV, with disagreements at higher energies

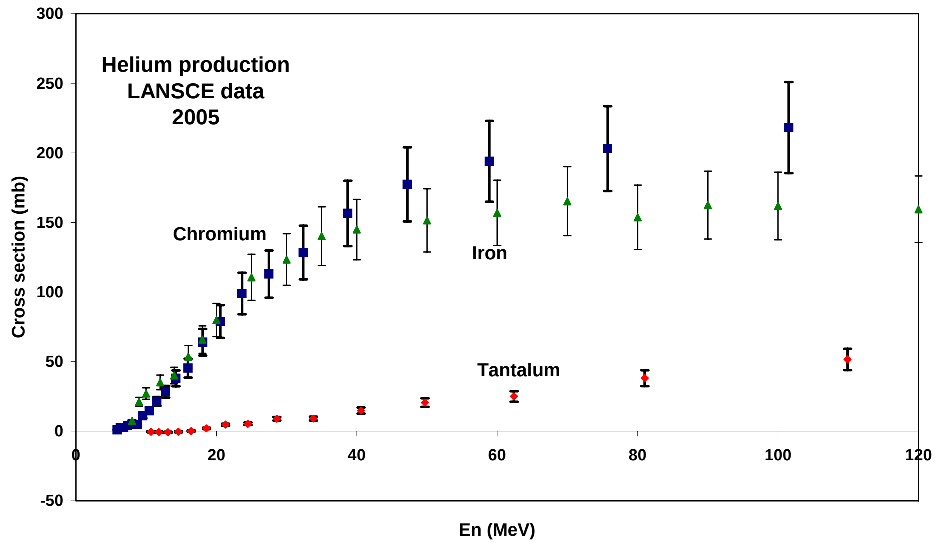


New results are for Chromium – here are results for Hydrogen production



- **Hydrogen production in chromium is very similar to that in iron**
- **Perhaps, no surprise: Z(Fe) = 26, Z(Cr) = 24**
- **Both excitation functions are flat above ~ 50 MeV**
- **Tantalum (Z=79) has much lower Hydrogen production cross section – but it increases with E_n at least to 110 MeV**

New results for Helium production in Chromium



- **Helium production in chromium is also very similar to that in iron (maybe a little larger)**
- **Perhaps, no surprise: Z(Fe) = 26, Z(Cr) = 24**
- **Both excitation functions are flat above ~ 50 MeV**
- **Tantalum (Z=79) has much lower Helium production cross section – but it increases with E_n at least to 110 MeV**

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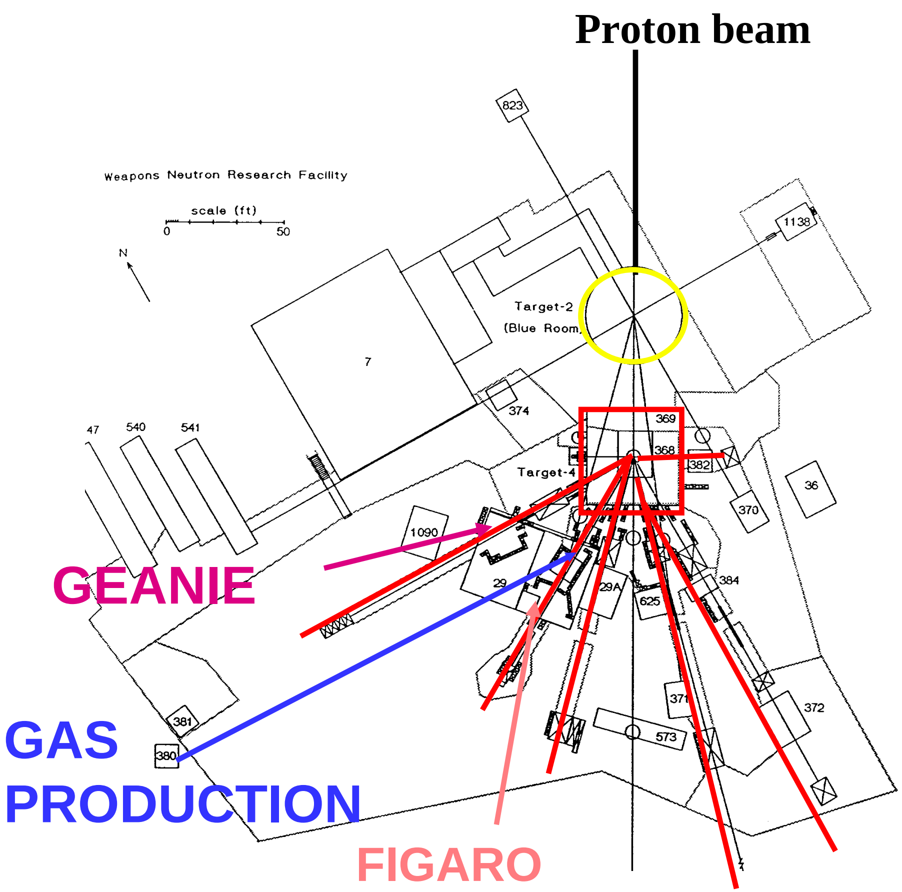
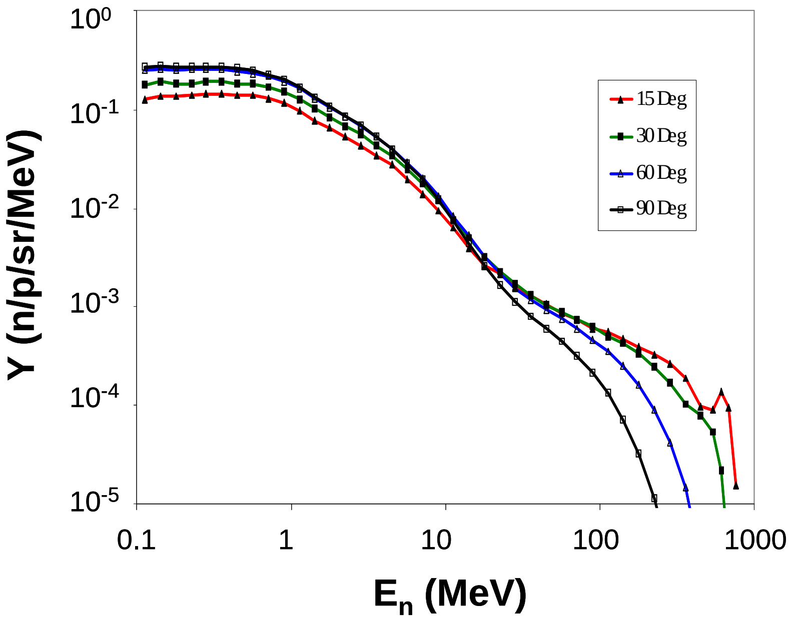
Summary

- New data for hydrogen and helium production by neutron interactions have been determined from threshold to 100 MeV
  - Cr, Fe, Ni, Ta, and (soon) Zr and Mo
- Experimental data are needed to improve nuclear reaction models and evaluated data libraries
- This technique is applicable to all materials that can be made into thin foils – therefore all structural materials and many other materials
- Some experimental improvements are underway; more are needed
- Question: Is 15-20% accuracy good enough for the long term?

We use the 30-degree flight path at WNR to enhance the number of neutrons above 20 MeV.



Neutron spectrum extends from 1 to ~ 300 MeV; more high energy neutrons at 30-degrees.



Gas production runs concurrently with FIGARO

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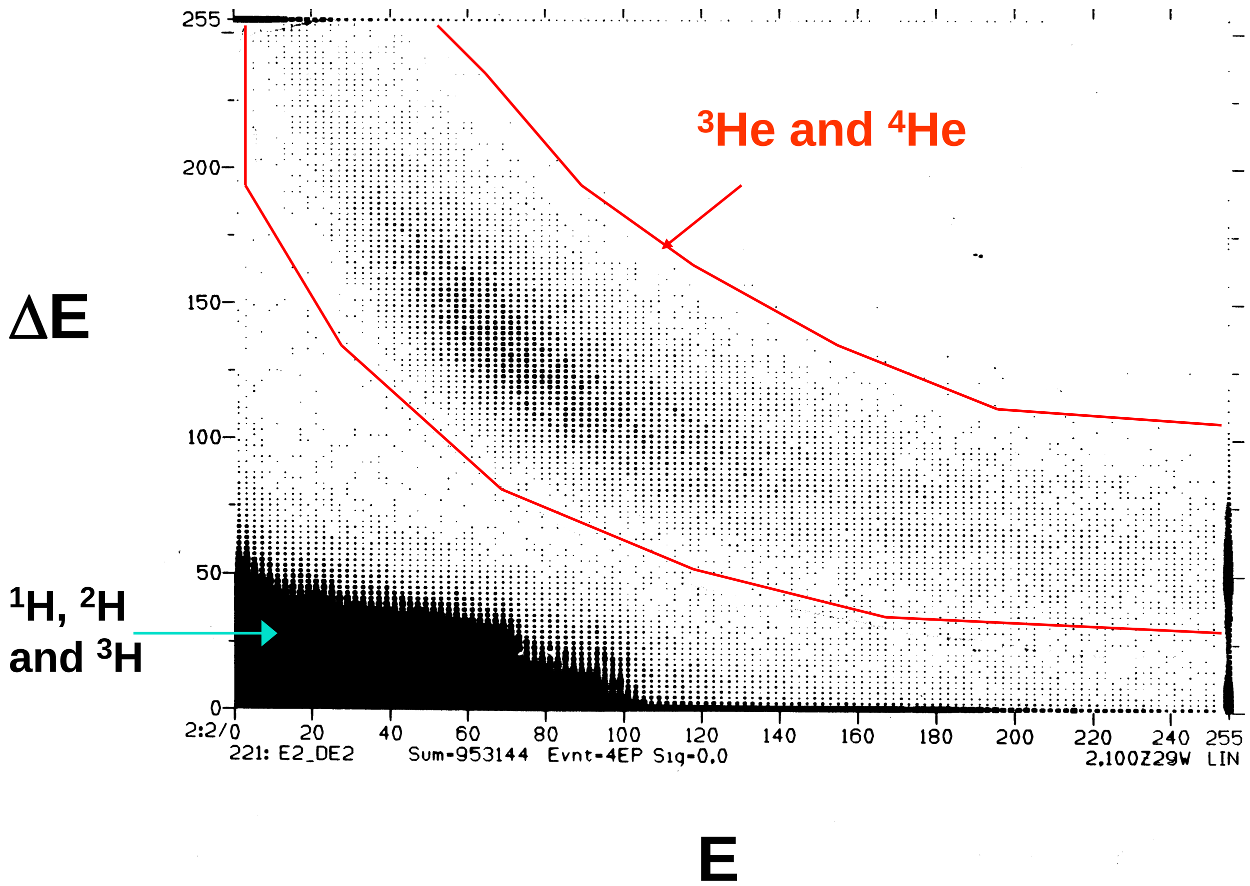
ΔE-E information allows us to separate particle types



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