LA-UR-03-3525

Abstract

Use of a beam-driven subcritical assembly is being explored as a possible way to consume the plutonium and minor actinides that are produced in fission reactors. One system under consideration uses a liquid lead-bismuth eutectic (LBE) for the neutron production target. Accurate calculation of the neutron yield is required for design of the surrounding subcritical assembly. To gather data on the neutron production, a large (40-cm-diam, 50-cm-long) LBE target was irradiated in the "Blue Room" facility at the Los Alamos Neutron Science Center. The target was irradiated with 800-MeV protons, and the neutron spectra were measured at various locations along the target using activation foils of bismuth, indium, cobalt, nickel, copper, iron, aluminum, and gold. The foils were placed in various locations on the surface of the target and irradiated for ~12 h. Immediate counting of the foils after the irradiation allowed sampling of the 0.5-MeV (n,n') threshold reaction from indium and many other reactions with thresholds of <10 MeV. In addition, the bismuth and terbium foils provided multiple (n,xn) reactions up to x = 10, with thresholds from 28 to 100 MeV. Overall, each foil packet yielded 30 to 40 useful reactions for determination of the neutron spectrum. The spectra were unfolded using the STAY'SL program and compared to MCNPX model calculations. Generally, the spectra agreed well with calculations, with only minor adjustments needed to fit the foil data. However, the neutron yield was less than predicted at the end of the target in the 40-cm and 50-cm locations. The difference was seen predominantly in the 1- to 3-MeV range from the indium (n,n') reaction.

Neutron Leakage Measurements on a Thick Pb-Bi Target

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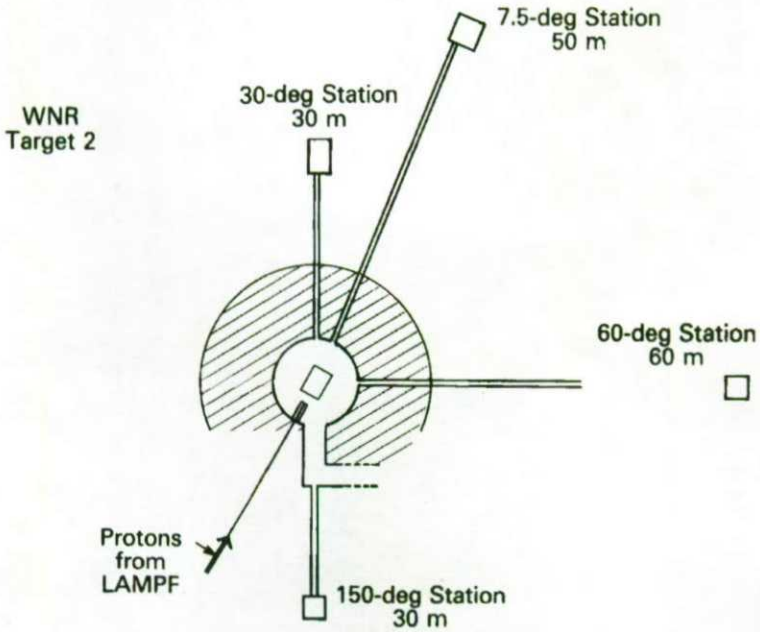
Neutron Yield Experiment Plan

- Irradiate various sizes of LBE targets and assess the neutron spectrum by a combination of TOF and activation foil analysis.
- Irradiate using 800-MeV protons in the WNR Blue Room.
- Limited shielding constrains maximum current to ~25 - 50 nA for stopping-length target.
- First experiments conducted in December 2001 with 20-cm-diameter target.

- Follow-up experiment on 40-cm-diameter target.
  - TOF done with 7.5°, 30°, 60°, and 150° beamlines.
  - 22 activation foils spaced along target in axial and radial directions.

LBE = lead-bismuth eutectic
TOF = time of flight
WNR = Weapons Neutron Research

Configuration of TOF and LBE Target



- Overhead schematic of neutron beamlines and placement of LBE target at the LANSCE WNR facility.

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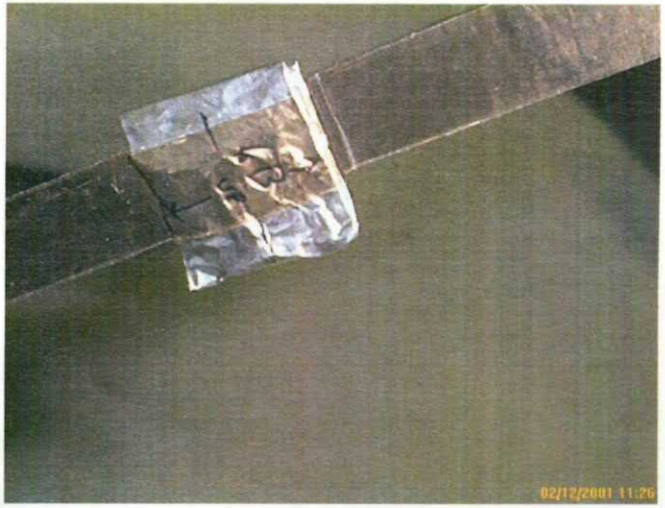
Activation Foil Packets
Assembly and Contents

- Al
- Au
- Bi
- Cd/Au*
- Co
- Cu
- Fe
- In
- Ni
- Tb*

* *Not present in all packets*



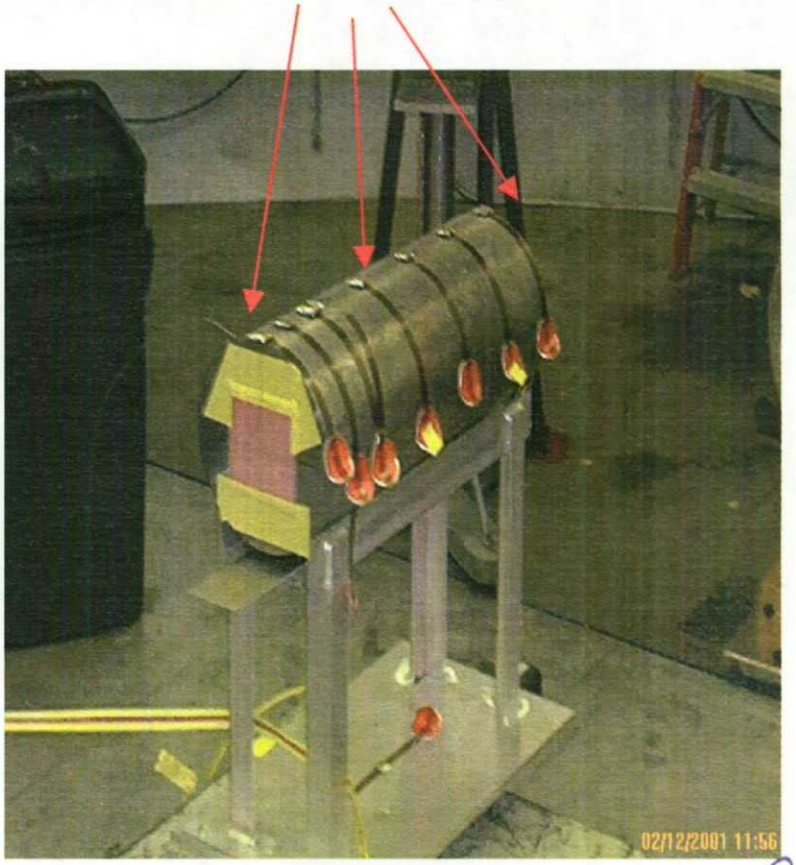
Foils wrapped in Al foil and secured to target with mylar tape. Foil dimensions approximately 1 cm x 1 cm x 0.25 mm.

Activation foil packets consisted of high-purity metals (>99.8%).

LBE Target Geometry

- Target used was 44.5 w/o Pb, 55.5 w/o Bi.
- 40-cm diameter.
- 48.875 cm long.
- Fully dense (no major voids present).
- Al structure held target 30 cm above the table.

Foils distributed at 0, 5, 10, 15, 20, 30, 40, and 50 cm and at 45° intervals at two locations.



Methodology

Foils counted after irradiation to determine activation levels present.

Modeling of targets performed to establish baseline estimates for neutron spectra.

Activities of isotopes converted to a saturation activity.

Fluences and activities combined in STAYSL to provide estimates of neutron spectra.

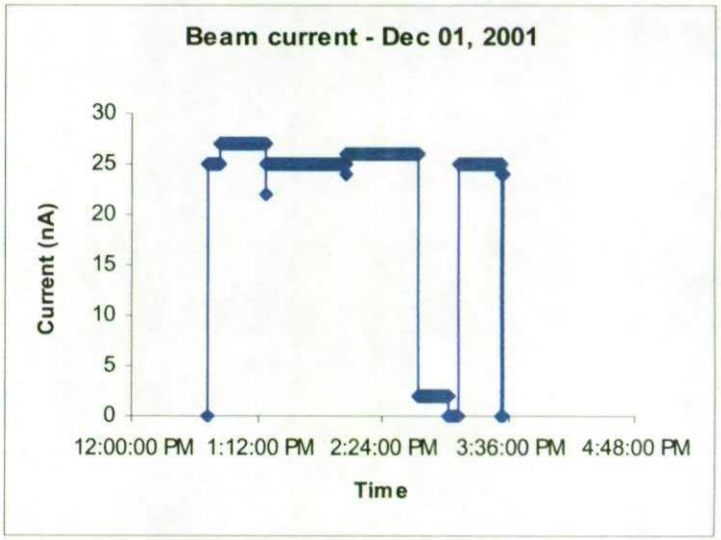
Conversion to Saturation Activities

Half-life determines relationship from T_0 activity to saturation activity

T(1/2)		LAMBDA (1/H)	NUCLIDE	EFLUX/AVGBM
2.6	Y	3.04E-05	NA22	8.66E-05
15.0	H	4.63E-02	Na24	1.23E-01
16.0	D	1.81E-03	V48	5.13E-03
83.8	D	3.45E-04	SC46	9.81E-04
43.7	H	1.59E-02	SC48	4.41E-02
27.7	D	1.04E-03	CR51	2.97E-03
5.6	D	5.17E-03	Mn52	1.46E-02
312.2	D	9.25E-05	MN54	2.64E-04
2.6	H	2.69E-01	Mn56	5.14E-01
44.5	D	6.49E-04	FE59	1.85E-03
17.5	H	3.95E-02	CO55	1.06E-01
77.3	D	3.74E-04	CO56	1.06E-03
271.8	D	1.06E-04	CO57	3.03E-04
70.9	D	4.07E-04	CO58	1.16E-03
5.3	Y	1.50E-05	CO60	4.28E-05

$$\alpha_{sat} = \frac{N_{A(ZT)} \cdot \lambda}{BCF} \cdot \left(\frac{MW}{mass \cdot A_v} \right)$$

- **BCF program used to calculate saturation activities.**
- **Comparison to approximation calculation.**
- **BCF uses beam history to compute ratio of activity at zero time to saturation activity.**



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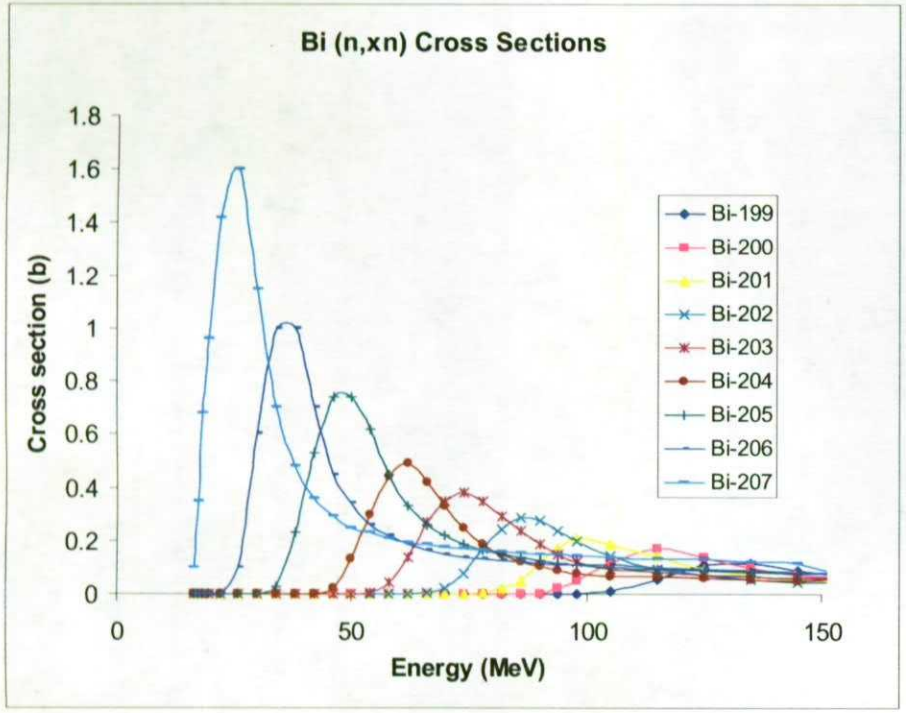
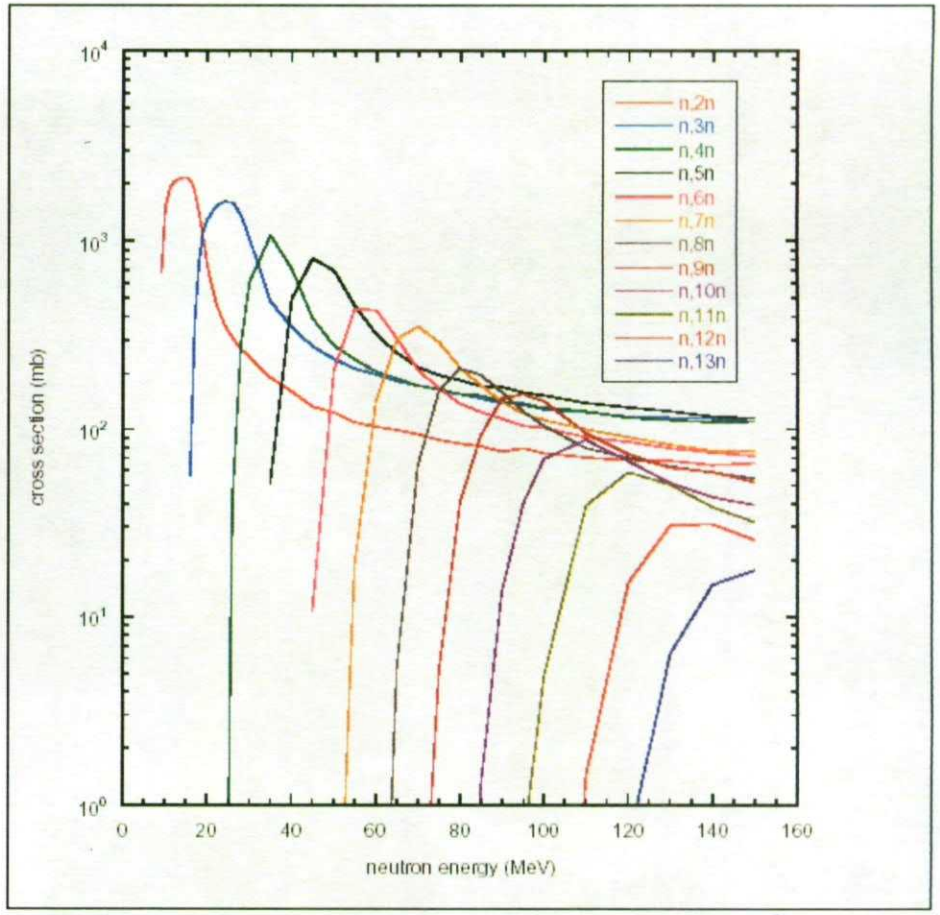
Cross Sections and Regions of Sensitivity

- **Low-energy neutron data from In(n,n´)In115, Fe(n,x)Mn54, Ni(n,x)Co58, Ni(n,x)Co60, and Cu(n,x)Co60.**
- **High-energy neutrons from Bi and Tb.**





Tb (n,xn) cross sections

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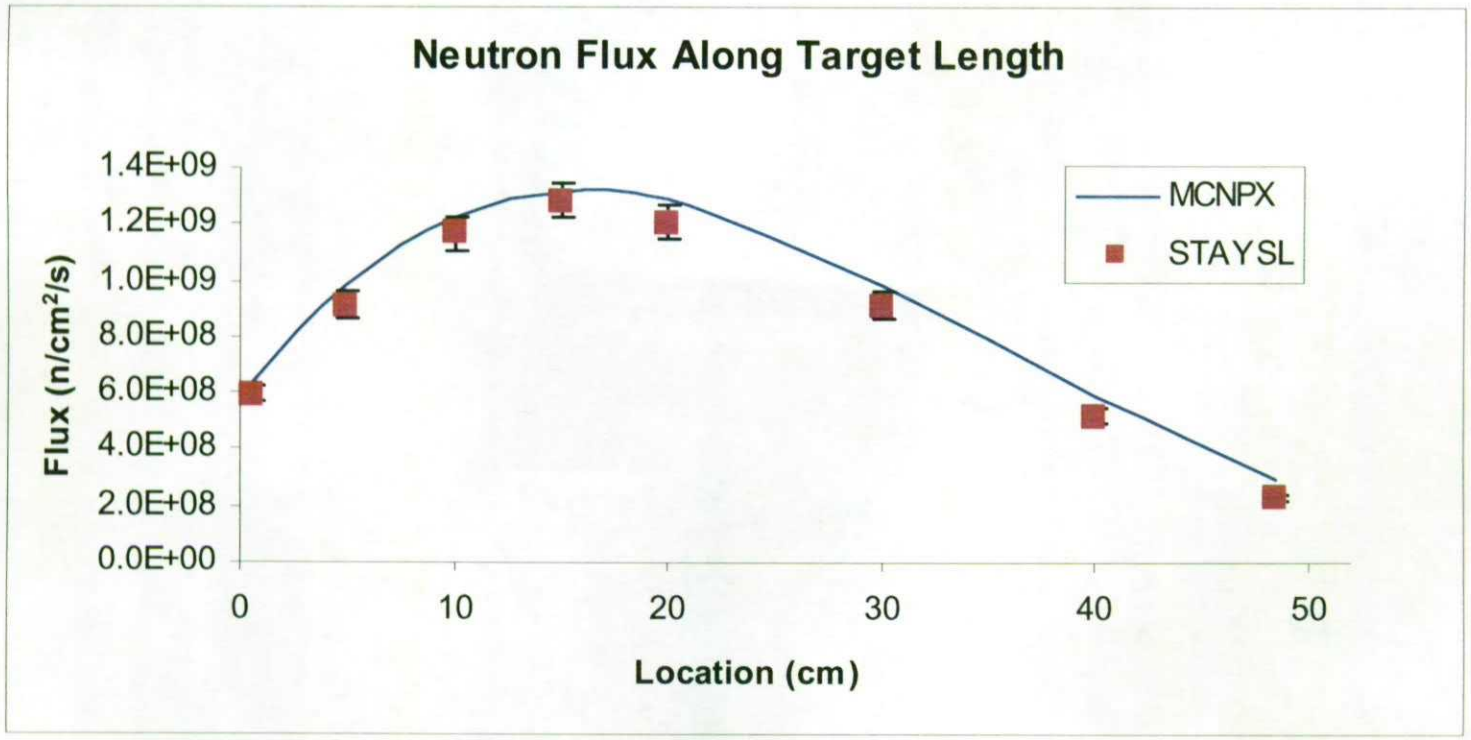
Results - Neutron Flux Peaks at ~15 cm
Fewer Neutrons at the Rear Face of Target



Flux calculations from foils agree with MCNPX calculations for the front and midtarget areas. Foils show decreasing flux level toward rear face of target with ~25% difference at last location. Statistical errors for MCNPX runs were < 1%.

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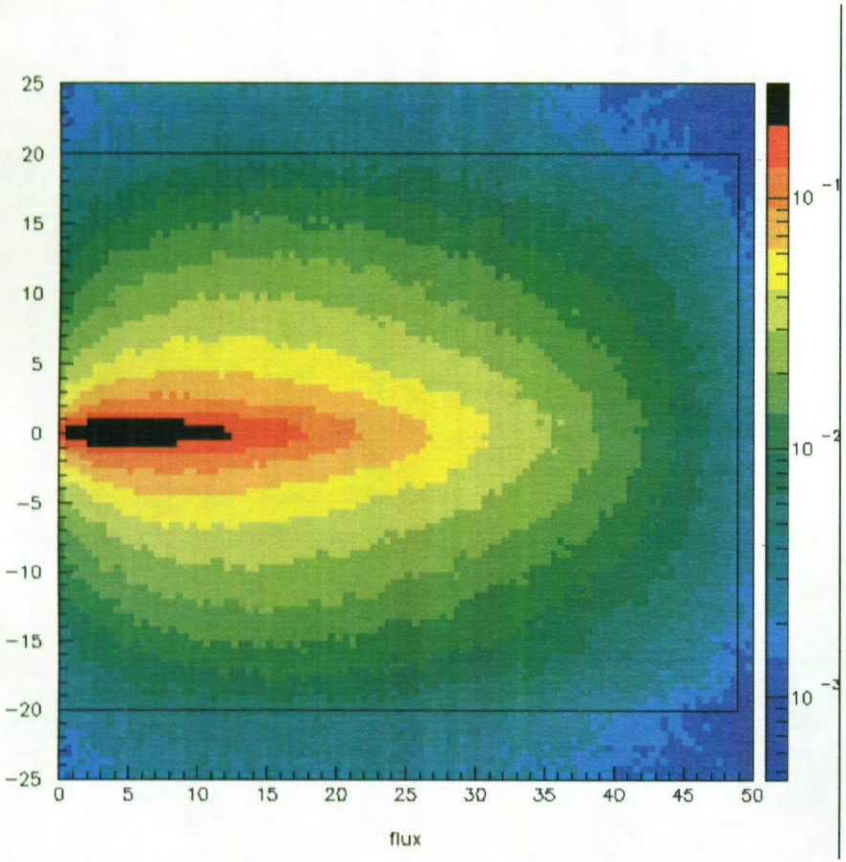
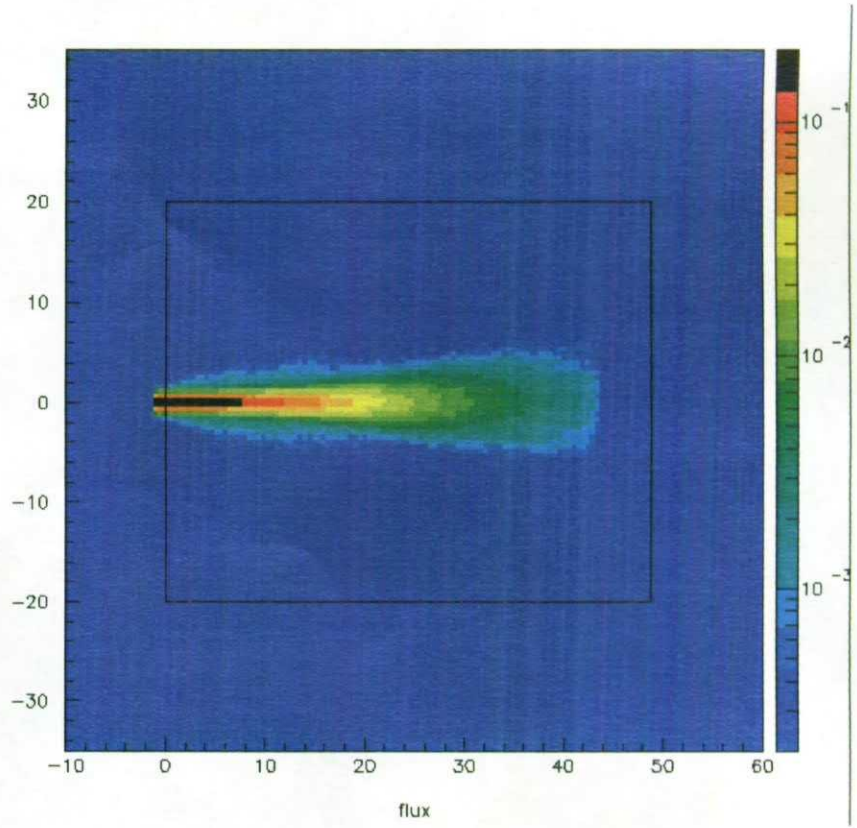
Proton and Neutron Fluxes in Target

- **Neutrons**



Protons



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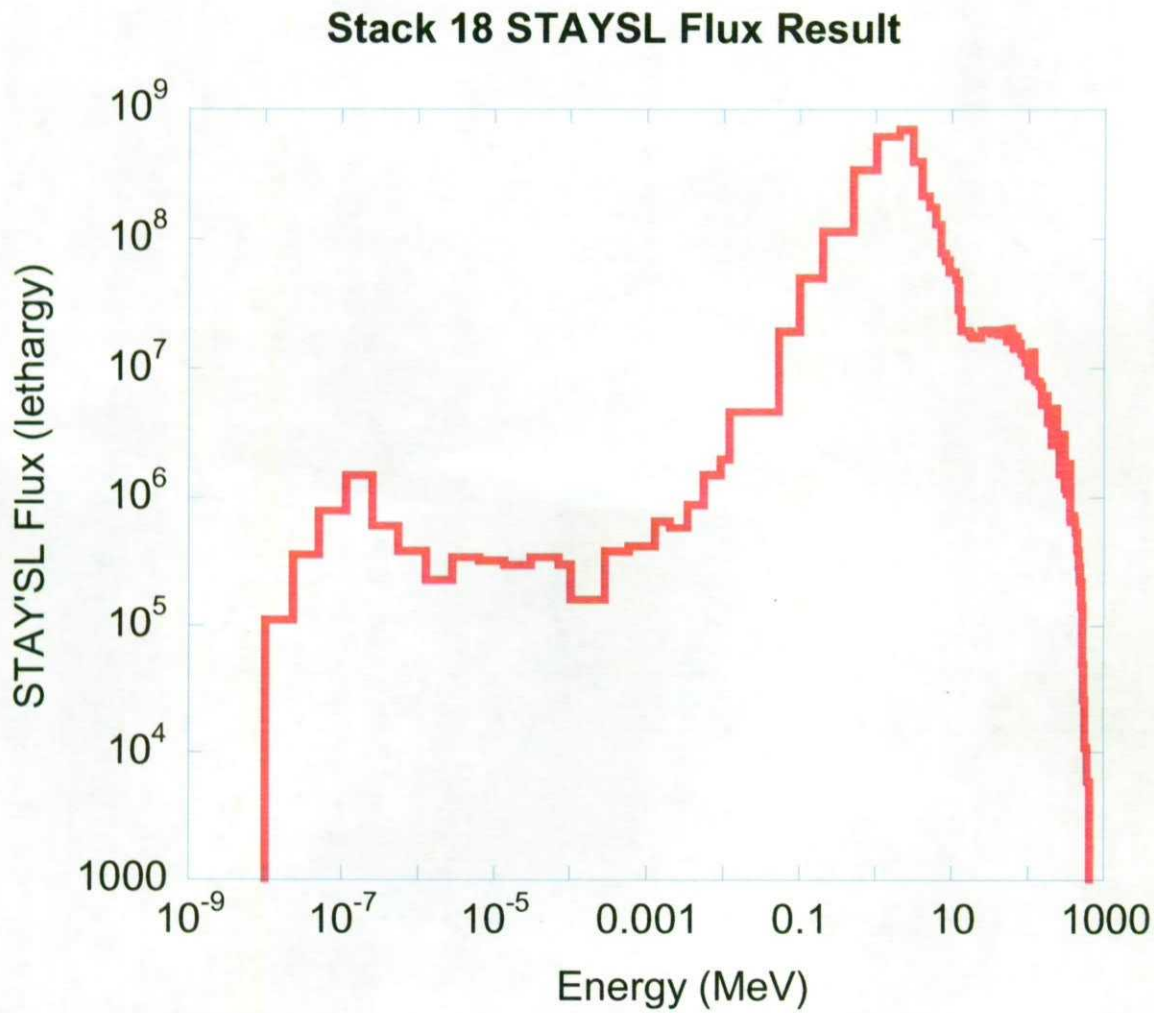
Example Spectrum – Stack 18



Spectrum determined with STAY'SL at surface of 40-cm target at Stack 18 position

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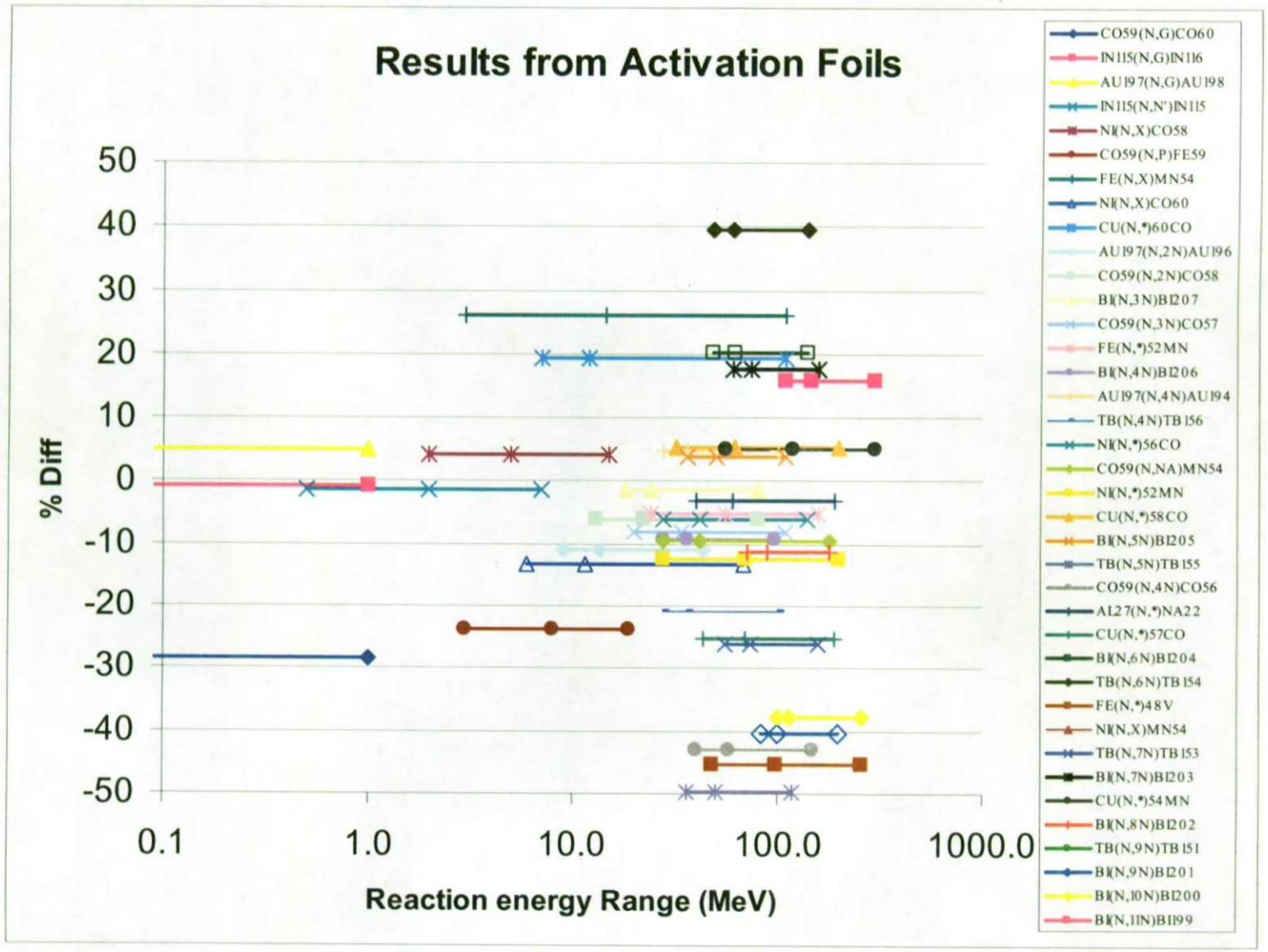
STAY'SL output showing reactions used and fidelity of each to the final neutron spectrum.

Reaction	Measured Activity	Error	Calculated activity	% Diff (C/E)	Chi	Lower Energy (MeV)	Upper Energy (MeV)	Midpoint
CO59(N,G)CO60 (	5.36E+07	5	6.83E+07	-27.5	1.4	1.00E-09	1.00E+00	5.00E-08
IN115(N,G)IN116 G	4.38E+08	5	4.42E+08	-0.8	0	1.00E-08	1.00E+00	9.13E-07
AU197(N,G)AU198	3.53E+08	5	3.36E+08	4.8	0.5	1.00E-08	1.00E+00	2.80E-06
IN115(N,N')IN115	1.57E+08	5	1.61E+08	-2.5	0	5.00E-01	7.00E+00	2.00E+00
NI(N,X)CO58	4.38E+07	5	4.20E+07	4.1	0.1	2.00E+00	1.50E+01	5.00E+00
CO59(N,P)FE59	1.83E+06	5	2.26E+06	-23.1	1.6	3.00E+00	1.90E+01	8.00E+00
FE(N,X)MN54	7.17E+06	10	5.05E+06	29.6	3.6	3.00E+00	1.10E+02	1.45E+01
NI(N,X)CO60	1.14E+06	10	1.26E+06	-9.9	0.3	6.00E+00	6.80E+01	1.15E+01
CU(N,*)60CO	1.23E+06	10	9.45E+05	23.4	1.7	7.00E+00	1.10E+02	1.20E+01
AU197(N,2N)AU19(	3.40E+07	5	3.65E+07	-7.4	0.2	9.00E+00	4.40E+01	1.35E+01
CO59(N,2N)CO58	1.57E+07	5	1.58E+07	-1.2	0	1.30E+01	8.00E+01	2.20E+01
BI(N,3N)BI207	2.08E+07	25	2.01E+07	3.5	0	1.80E+01	8.00E+01	2.40E+01
CO59(N,3N)CO57	4.08E+06	5	4.11E+06	-0.6	0	2.00E+01	1.10E+02	3.40E+01
FE(N,*)52MN	3.53E+05	10	3.28E+05	7	0	2.40E+01	1.60E+02	5.60E+01
BI(N,4N)BI206	9.93E+06	10	1.02E+07	-2.8	0.1	2.80E+01	9.60E+01	3.60E+01
AU197(N,4N)AU19(	1.17E+07	5	1.05E+07	10.5	0.2	2.80E+01	1.00E+02	3.60E+01
TB(N,4N)TB156	8.76E+06	20	9.93E+06	-13.3	0.7	2.80E+01	1.00E+02	3.60E+01
NI(N,*)56CO	2.26E+06	5	2.23E+06	1.6	0	2.80E+01	1.40E+02	4.20E+01
CO59(N,NA)MN54	1.43E+06	10	1.40E+06	1.7	0	2.80E+01	1.80E+02	4.20E+01
NI(N,*)52MN	2.71E+05	10	2.57E+05	4.9	0	2.80E+01	2.00E+02	7.00E+01
CU(N,*)58CO	1.35E+06	5	1.10E+06	18.5	0.1	3.20E+01	2.00E+02	6.20E+01
BI(N,5N)BI205	7.70E+06	10	6.83E+06	11.4	0.1	3.60E+01	1.10E+02	5.00E+01
TB(N,5N)TB155	5.22E+06	20	7.16E+06	-37.2	4.7	3.60E+01	1.20E+02	5.00E+01
CO59(N,4N)CO56	4.56E+05	5	5.79E+05	-27	1	4.00E+01	1.50E+02	5.80E+01
AL27(N,*)NA22	3.45E+05	20	3.09E+05	10.3	0	4.00E+01	1.90E+02	6.00E+01
CU(N,*)57CO	6.32E+05	5	6.76E+05	-7	0.6	4.40E+01	1.90E+02	7.00E+01
BI(N,6N)BI204	4.67E+06	10	3.30E+06	29.3	1.8	4.80E+01	1.40E+02	6.20E+01
TB(N,6N)TB154	6.03E+06	20	3.24E+06	46.2	4.5	4.80E+01	1.40E+02	6.00E+01
FE(N,*)48V	1.59E+05	10	1.83E+05	-14.9	0.6	4.80E+01	2.60E+02	9.80E+01
NI(N,X)MN54	1.09E+05	10	3.69E+05	-237.3	2.8	5.20E+01	2.20E+02	8.40E+01
TB(N,7N)TB153	2.09E+06	20	2.24E+06	-7	0.5	5.60E+01	1.60E+02	7.40E+01
CU(N,*)54MN	1.78E+05	15	1.30E+05	26.9	0.2	5.60E+01	3.00E+02	1.20E+02
BI(N,7N)BI203	3.23E+06	10	2.26E+06	30.2	1.5	6.00E+01	1.60E+02	7.40E+01
BI(N,8N)BI202	1.46E+06	10	1.29E+06	11.4	0.2	7.20E+01	1.80E+02	9.00E+01
TB(N,9N)TB151	5.60E+05	20	7.06E+05	-26.2	4.2	8.00E+01	2.00E+02	9.80E+01
BI(N,9N)BI201	7.79E+05	10	8.30E+05	-6.6	0.3	8.40E+01	2.00E+02	1.00E+02
BI(N,10N)BI200	6.21E+05	15	6.28E+05	-1.2	0	1.00E+02	2.60E+02	1.15E+02
BI(N,11N)BI199	6.71E+05	40	4.07E+05	39.3	0.3	1.10E+02	3.00E+02	1.45E+02

% Diff (C/E) Increases at Higher Energies



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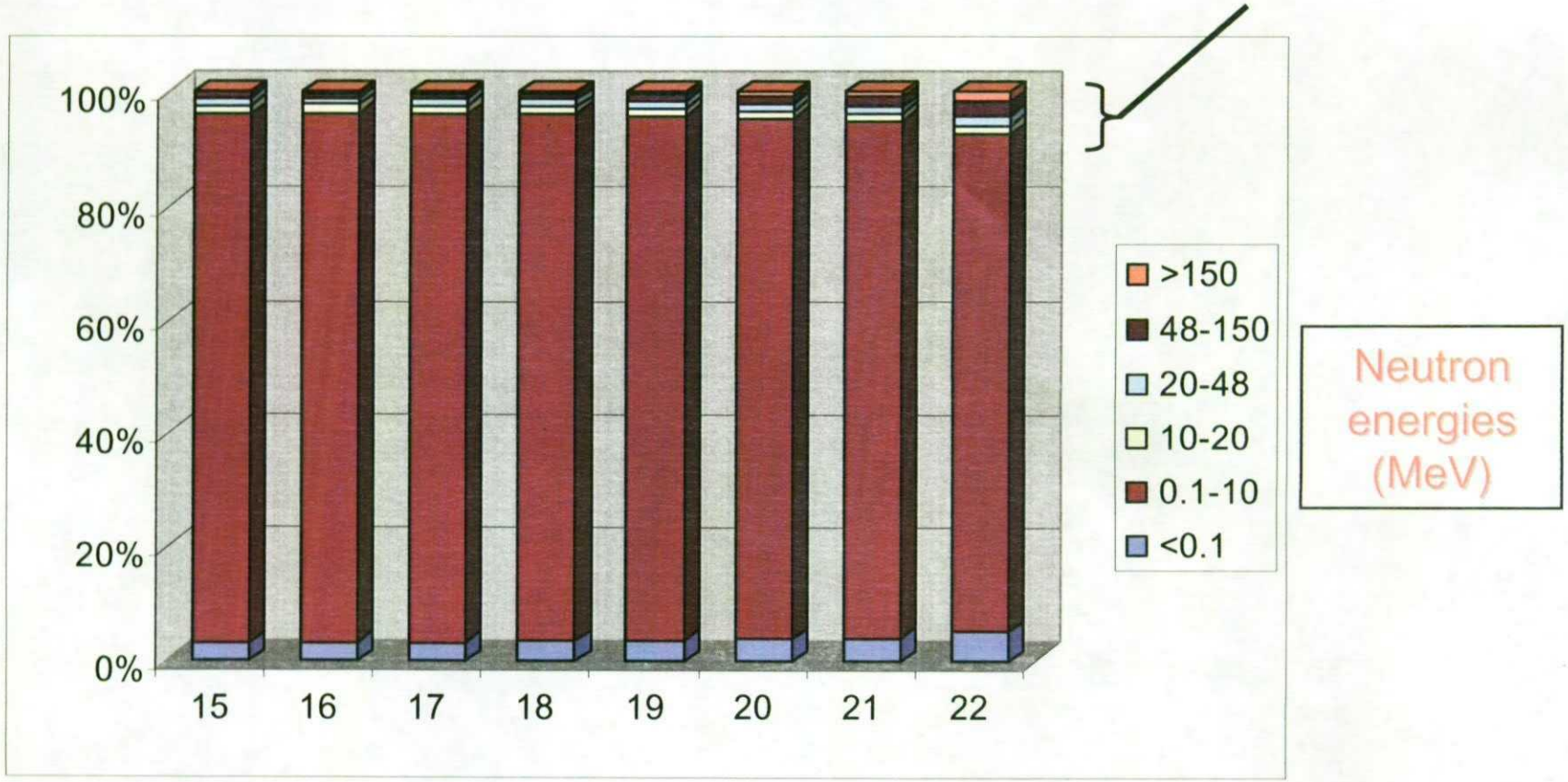
Results - Harder Spectrum toward Rear of Target
Most Neutrons between 0.1 and 10 MeV

More than 85% of flux between 0.1 and 10 MeV

Fraction of neutrons at higher energies increases toward rear of target



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Summary

- Most foil stacks across length of the targets have been analyzed.
  - The 40-cm target data overall show good agreement near the front and midpoint of target.
  - Toward the rear face, the foils show ~25% less neutron flux than expected.
  - Results show progressively harder spectrum toward rear of target.
  - Propagation of neutrons through LBE may be difference in the two results.
- Bi isotopes down to Bi-200 (n,10n) detectable.
  - Bi-199 is dubious value.
- Tb foils seem to require some work to make useful.
  - Reactions down to (n,10n) also detected.
  - Some conflicts in activity levels with expectations, work needed to measure cross sections.

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