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Preliminary Neutron Measurements on a Thick Pb-Bi Target

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"Blue Room" (WNR Target 2)

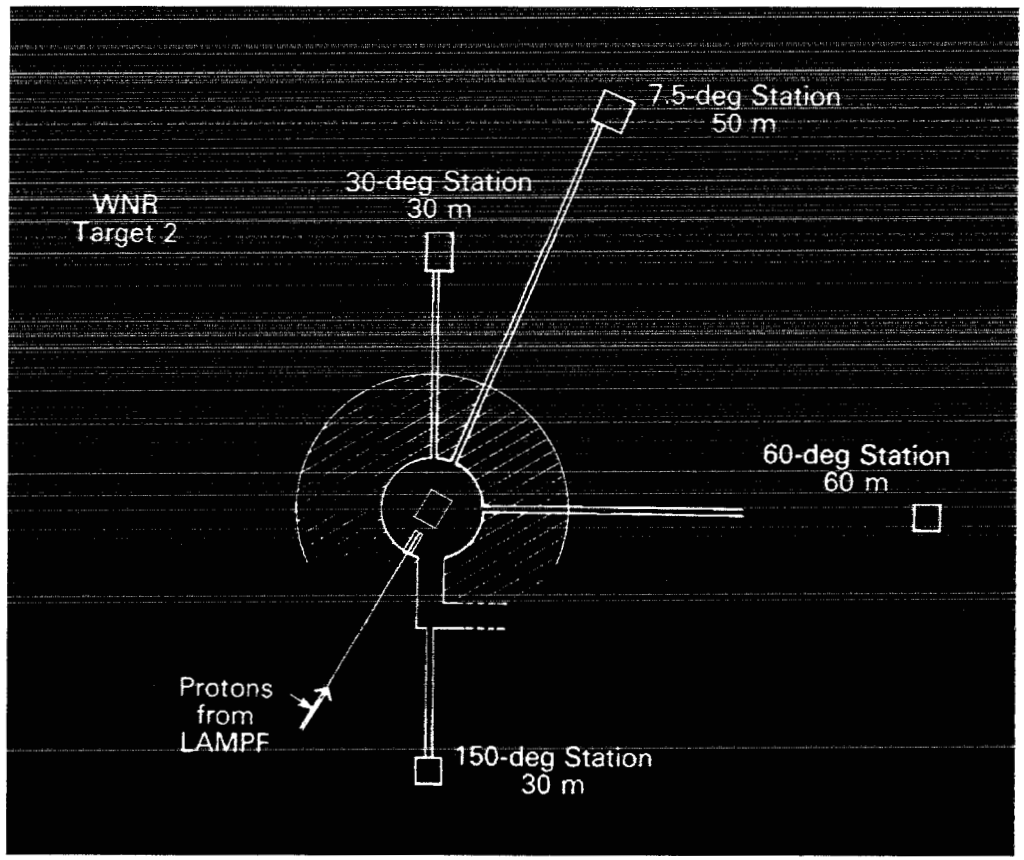
- Experimental plan to irradiate various sizes of LBE targets and assess the neutron spectrum by a combination of TOF and activation foil analysis.

- Experiments to be conducted using 800 MeV protons in the WNR Blue Room.
- Shielding of room limits the maximum current to ~ 25 nA for stopping-length target

- First experiments conducted in December, 2001 with 10-cm radius target.
  - TOF done with 7.5° and 30° beamlines.
  - Activation foils spaced along target in axial and radial directions.

Configuration of TOF and LBE Target

- Overhead schematic of neutron beamlines and placement of LBE target



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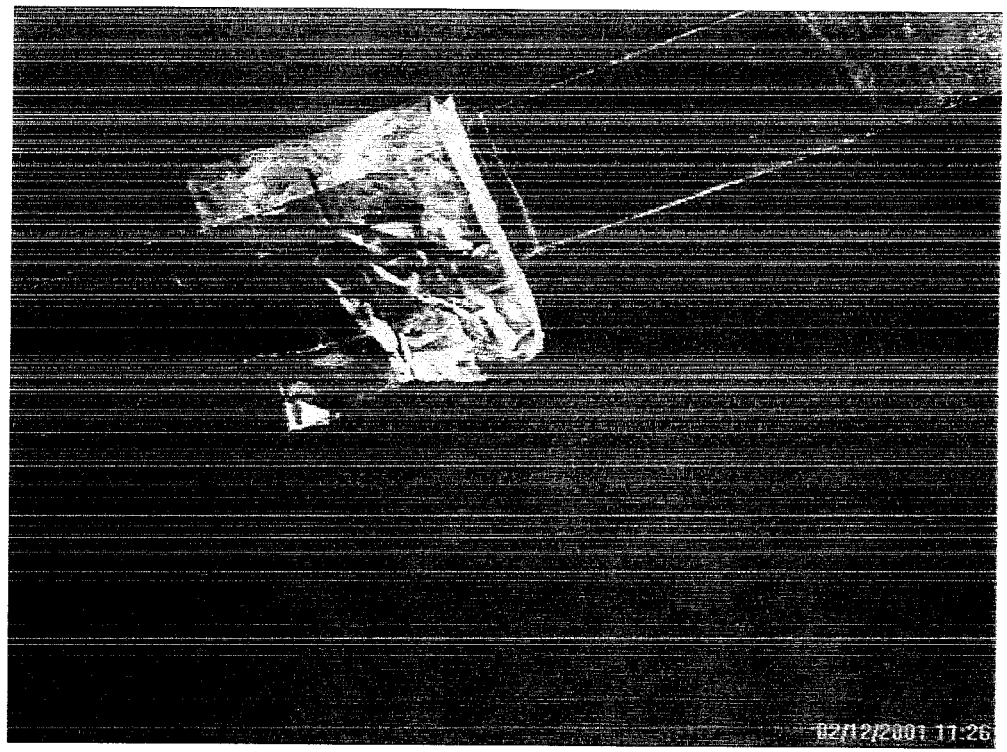
Activation Foil Packets

Activation foil packets consisted of pure metals (>99.8 %):

- Al
- Au
- Bi
- Cd/Au*
- Co
- Cu
- Fe
- In
- Lu
- Nb
- Ni
- Rh*
- Tb*
- Ti
- Zn

** 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 0.25mm

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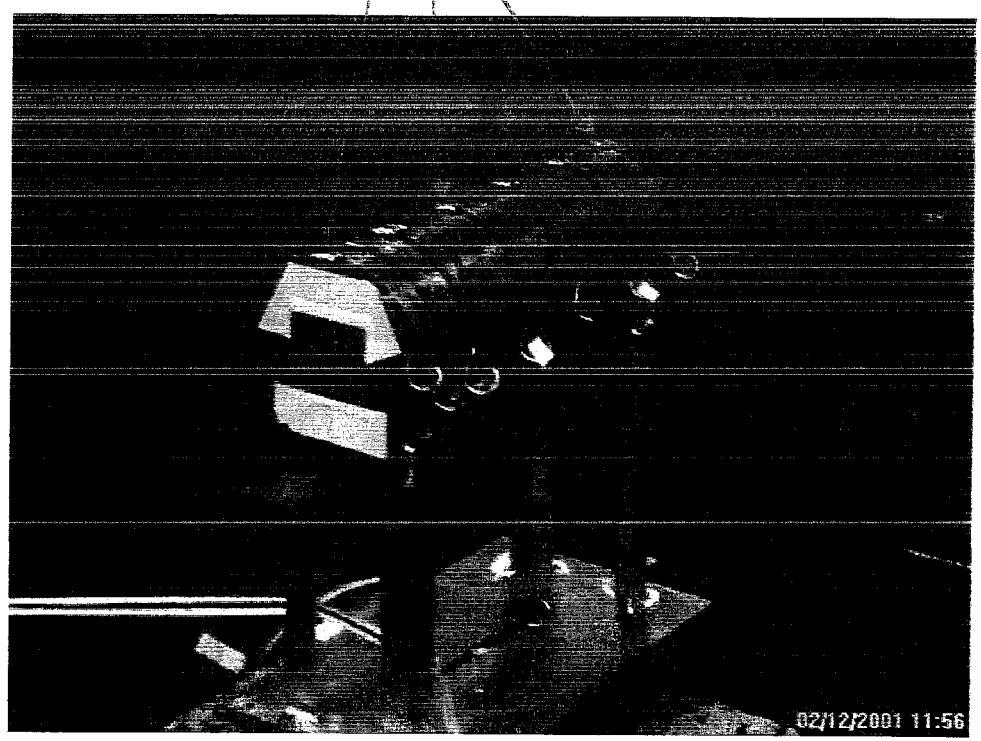
LBE Target Geometry

- ⇨ Target used was 44.5% Pb, 55.5 % Bi.
- ⇨ 10.16 cm radius.
- ⇨ 50 cm long.
- ⇨ Fully dense (no major voids present).
- ⇨ Al structure help target 30cm above the table.

Foils distributed at 0, 5, 10, 20, 30, 40, and 50 cm and at 90° intervals at 10-cm location.



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Methodology

Foils counted after irradiation to determine activation levels present.

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

Activities of isotopes converted to a saturation activity.

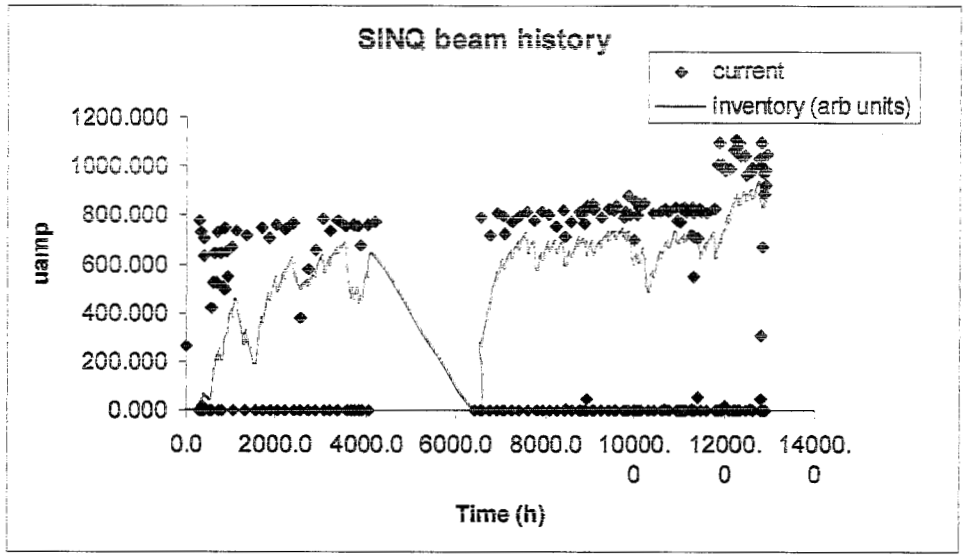
Fluences and activities combined in STAYSL to provide estimates of combined proton and neutron spectra.

Conversion to Saturation activities

Half-life determines relationship from T_0 activity to saturation activity

- **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.**

NUCLIDE	EFLUXAVGB	(1-E(-LT))	RATIO	Adjusted BC
NA22	3.36E-01	3.25E-01	1.0361	0.1447
BE07	1.47E+00	9.99E-01	1.4754	0.6340
V48	1.64E+00	1.00E+00	1.6449	0.7075
TI44	2.07E-02	2.06E-02	1.0019	0.0089
SC46	1.35E+00	9.88E-01	1.3663	0.5808
CR51	1.59E+00	1.00E+00	1.5905	0.6841
MN54	7.75E-01	6.97E-01	1.1117	0.3333
FE59	1.51E+00	1.00E+00	1.5126	0.6504
CO56	1.38E+00	9.92E-01	1.3867	0.5917
CO57	8.42E-01	7.46E-01	1.1284	0.3622
CO58	1.40E+00	9.95E-01	1.4084	0.6026
CO60	1.79E-01	1.76E-01	1.0177	0.0771
NB92	1.65E+00	1.00E+00	1.6464	0.7081
NB93	6.17E-02	6.13E-02	1.0058	0.0265
NB94	5.03E-04	5.03E-04	1	0.000216
SE75	1.22E+00	9.55E-01	1.2778	0.5251
ZN65	8.94E-01	7.83E-01	1.1428	0.3847
RB83	1.34E+00	9.87E-01	1.3591	0.5768
SR85	1.43E+00	9.97E-01	1.4302	0.6132
A110	8.83E-01	7.75E-01	1.1395	0.3798
P143	8.54E-01	7.55E-01	1.1317	0.3675
H172	4.42E-01	4.21E-01	1.0505	0.1901
C144	8.20E-01	7.30E-01	1.1226	0.3525
T182	1.24E+00	9.62E-01	1.2886	0.5329
I192	1.39E+00	9.94E-01	1.3984	0.5976
A195	1.03E+00	8.65E-01	1.1861	0.4413



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

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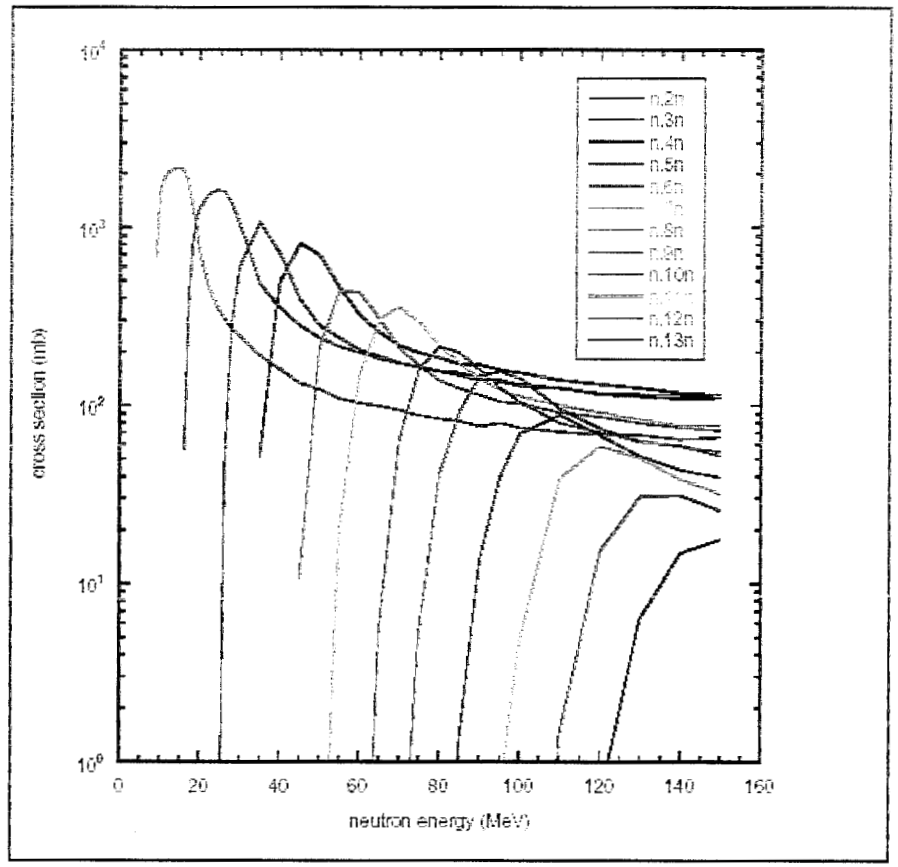
Cross sections and regions of sensitivity

- Low energy neutron data from Fe->Mn54, Ni->Co58, Ni->Co60, and Cu->Co60.
- High-energy neutrons from Bi, Tb.

Tb (n,xn) cross sections



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STAYSL Results - Packet 6

Minimize DIF % of important reactions

DOSIMETRY ACTIVITIES

	MEASURED	+/-%	BEFORE	DIF%	AFTER	DIF%	CHI	REACTION	90 % LIMITS	
1	3.81E+05	20.0	2.91E+05	23.6	2.93E+05	23.2	0.8	AL27(N,*)NA22	4.00E+01	1.70E+02
2	4.82E+04	15.0	2.44E+04	49.3	2.54E+04	47.2	4.0	FE(N,*)46SC	5.60E+01	2.80E+02
3	8.71E+04	10.0	1.72E+05	-97.1	1.76E+05	-102.0	4.9	FE(N,*)48V	4.80E+01	2.20E+02
4	2.74E+05	10.0	3.18E+05	-16.1	3.18E+05	-15.8	0.2	FE(N,*)52MN	2.40E+01	1.50E+02
5	8.27E+06	10.0	5.10E+06	38.3	5.20E+06	37.1	8.2	FE(N,X)MN54	3.00E+00	1.10E+02
6	2.64E+06	5.0	2.84E+06	-7.7	2.89E+06	-9.4	0.3	CO59(N,P)FE59	3.00E+00	1.90E+01
7	1.18E+06	10.0	1.37E+06	-15.8	1.35E+06	-14.7	0.2	CO59(N,NA)MN54	2.80E+01	1.60E+02
8	1.81E+07	5.0	2.18E+07	-20.5	2.12E+07	-17.5	1.4	CO59(N,2N)CO58	1.30E+01	6.80E+01
9	3.80E+06	5.0	4.21E+06	-10.8	4.12E+06	-8.5	0.6	CO59(N,3N)CO57	2.00E+01	1.10E+02
10	7.22E+05	5.0	5.43E+05	24.8	5.45E+05	24.5	1.7	CO59(N,4N)CO56	4.00E+01	1.40E+02
11	1.76E+07	5.0	1.67E+07	5.1	1.63E+07	7.3	0.1	CO59(N,G)CO60	1.00E-04	2.00E+00
12	1.92E+05	10.0	3.54E+05	-84.3	3.61E+05	-87.8	1.4	NI(N,X)MN54	5.20E+01	2.00E+02
13	1.95E+05	10.0	2.50E+05	-28.5	2.52E+05	-29.2	0.5	NI(N,*)52MN	2.40E+01	1.80E+02
14	2.07E+06	10.0	2.16E+06	-4.2	2.12E+06	-2.6	0.0	NI(N,*)56CO	2.80E+01	1.30E+02
15	5.64E+07	5.0	4.39E+07	22.2	4.53E+07	19.6	2.9	NI(N,X)CO58	2.00E+00	1.60E+01
16	1.82E+06	5.0	1.59E+06	12.5	1.59E+06	12.2	0.7	NI(N,X)CO60	6.00E+00	6.00E+01
17	1.02E+04	20.0	6.83E+03	33.2	7.46E+03	27.0	2.0	CU(N,*)48V	1.10E+02	3.60E+02
18	1.59E+05	10.0	1.18E+05	25.7	1.22E+05	23.0	1.2	CU(N,*)54MN	5.60E+01	2.60E+02
19	1.99E+05	10.0	1.38E+05	30.4	1.42E+05	28.7	4.6	CU(N,*)56CO	6.00E+01	2.20E+02
20	4.60E+05	5.0	6.43E+05	-39.9	6.50E+05	-41.4	4.1	CU(N,*)57CO	4.40E+01	1.70E+02
21	1.16E+06	5.0	1.05E+06	8.8	1.06E+06	8.5	0.1	CU(N,*)58CO	3.20E+01	1.80E+02
22	1.14E+07	5.0	1.44E+07	-26.4	1.42E+07	-24.7	1.3	NB93(N,2N)NB92M	1.00E+01	5.20E+01
23	6.81E+06	10.0	8.20E+06	-20.4	8.13E+06	-19.3	0.5	LU(N,X)LU171	3.60E+01	1.10E+02
24	9.91E+06	10.0	1.04E+07	-5.3	1.02E+07	-3.0	0.0	LU(N,X)LU172	2.40E+01	8.80E+01
25	1.16E+07	5.0	1.04E+07	10.1	1.02E+07	12.1	0.5	AU197(N,4N)AU194	2.80E+01	1.00E+02
26	4.78E+07	5.0	5.69E+07	-18.9	5.64E+07	-17.9	0.7	AU197(N,2N)AU196	9.00E+00	2.80E+01
27	1.10E+08	5.0	1.28E+08	-16.8	1.24E+08	-13.0	1.9	AU197(N,G)AU198	2.80E-06	2.00E+00
28	3.50E+05	10.0	6.04E+05	-72.6	6.23E+05	-78.1	3.7	BI(N,10N)BI200	9.60E+01	2.20E+02
29	8.53E+05	10.0	8.35E+05	2.1	8.53E+05	0.0	0.0	BI(N,9N)BI201	8.40E+01	1.80E+02
30	1.24E+06	10.0	1.30E+06	-5.2	1.32E+06	-7.1	0.1	BI(N,8N)BI202	7.20E+01	1.60E+02
31	3.06E+06	10.0	2.22E+06	27.3	2.25E+06	26.3	2.4	BI(N,7N)BI203	6.00E+01	1.50E+02
32	3.04E+06	10.0	3.11E+06	-2.5	3.14E+06	-3.2	0.0	BI(N,6N)BI204	4.80E+01	1.30E+02
33	9.03E+06	10.0	6.34E+06	29.8	6.30E+06	30.2	3.2	BI(N,5N)BI205	3.60E+01	1.10E+02
34	1.30E+07	10.0	1.01E+07	22.5	9.86E+06	24.1	1.7	BI(N,4N)BI206	2.80E+01	9.60E+01

Degree of discrepancy between foil activities and spectra

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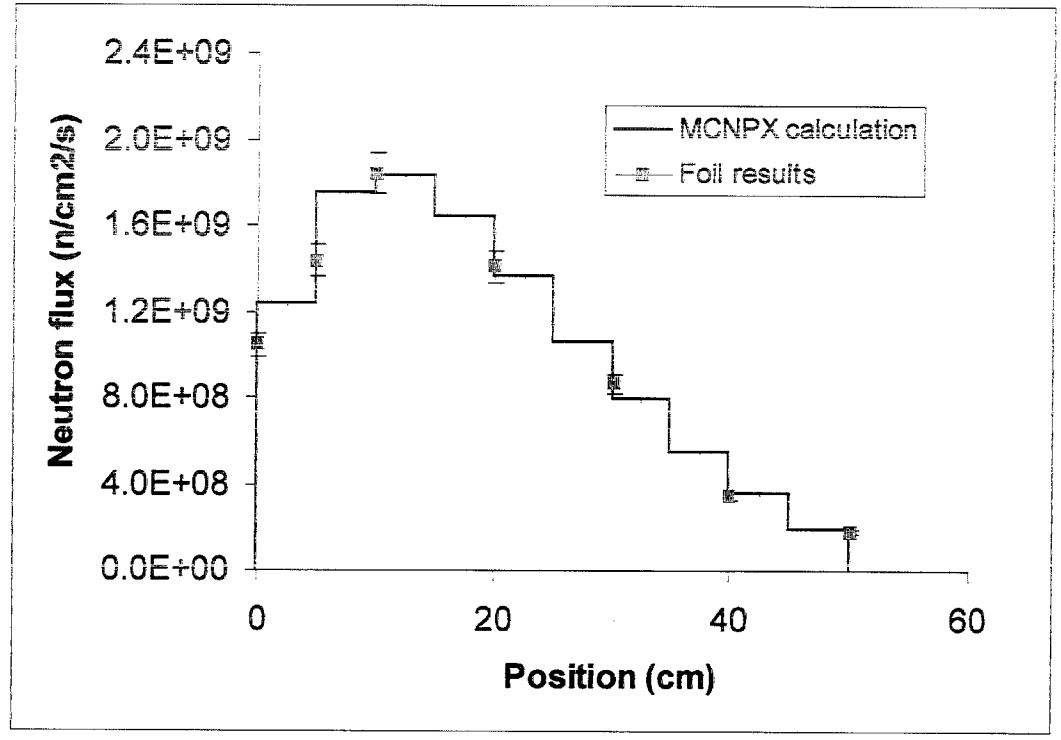
Results - Activation Foils confirm MCNPX calculations
Neutron Flux peaks at ~10cm

Flux calculations from foils agree with MCNPX calculations
Statistical errors for MCNPX runs were < 1%.



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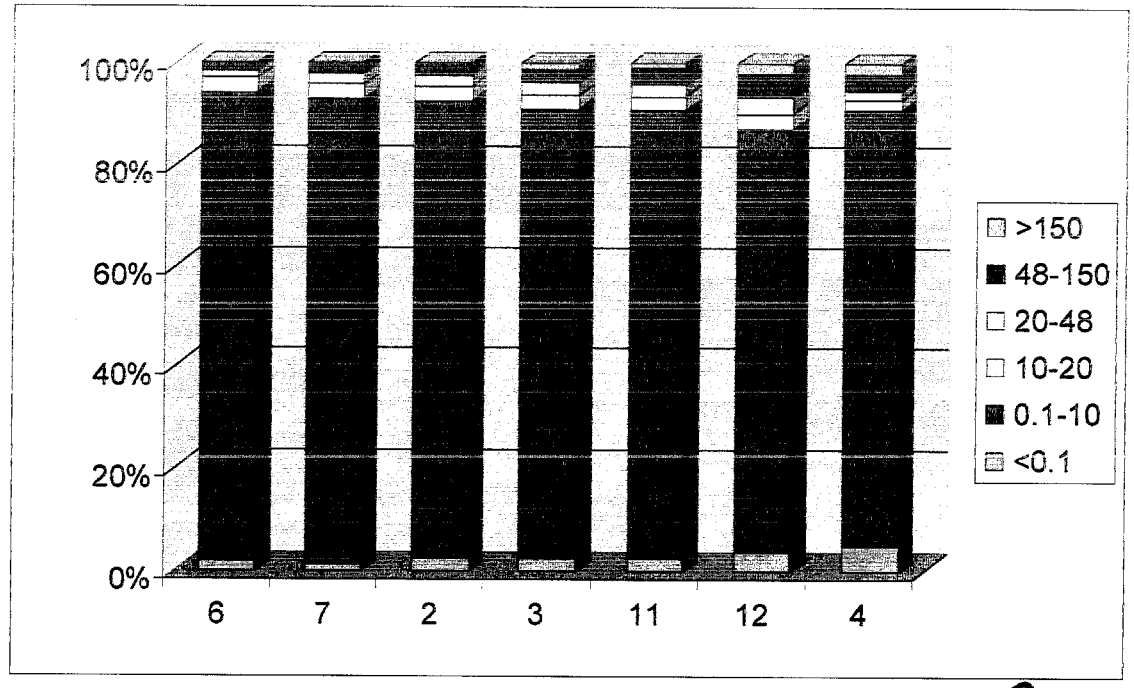
Results - Harder spectrum towards rear of target
Most neutrons between 0.1 and 10 MeV

More than 80% of flux between 0.1 and 10 MeV

Fraction of neutrons as higher energies increases towards rear of target



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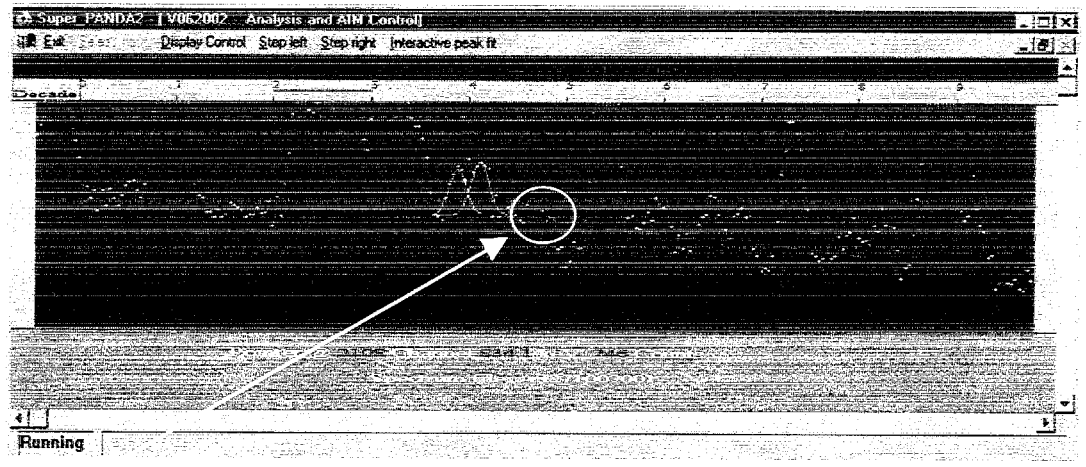
Results - Bi isotopes
Useful data up to n,10n

Bi isotopes down to Bi-200 can be measured.

Bi-199 is at limit of usefulness.

Gamma Line (keV)	Intensity	Comment
411.80	82%	Also Tl-198(m)
425.30	22%	Also Tl-196(m)
841.70	11%	Very weak
1135.00	7.8%	Also Pb-199



Detectable lines of Bi-199 are usually interference lines from other isotopes or are too weak to be used.

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Summary

- Initial results from LBE Target show the activation foils
  - Work
  - Have numerous isotopes even from low flux environment
  - Fit known spectrum well.
- Results show progressively harder spectrum towards rear of target.
- Bi isotopes down to Bi-200 (n,10n) detectable.
  - Bi-199 is dubious value
- Tb foils also seemed to be effective
  - Reactions down to (n,10n) also seen.
  - Isotopes relatively easy to detect (strong gammas, few overlaps)
  - Cross sections/activities match expectations

Future Work

- Just completed a similar irradiation of 40cm _ target.
- Analysis of foil stacks from both LBE targets is continuing.
- Irradiation is planned for January 2003 to apply same procedure for 5-cm diameter target.
- Further verification of cross sections, especially at high energies.

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