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TITLE: SHIELDING THE LANSCE 800-MEV SPALLATION NEUTRON SOURCE

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Shielding the LANSCE 800-MeV Spallation Neutron Source

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ABSTRACT

Neutrons produced by medium-energy (800-MeV) proton reactions at the Los Alamos Neutron Scattering Center spallation neutron source cause a variety of difficult shield problems. We describe the general shielding questions encountered at such a spallation source, and contrast spallation and reactor source shielding issues using an infinite slab-shield composed of 100 cm of iron and 15 cm of borated polyethylene. The calculations show that (for an incident spallation spectrum characteristic of neutrons leaking at 90 degrees from a tungsten target) high-energy neutrons dominate the dose at the shield surface. Secondary low-energy neutrons (produced by high-energy neutron attenuation) and attendant gamma-rays add significantly to the dose. The primary low-energy neutrons produced directly at the tungsten source contribute negligibly to the dose, and behave similarly to neutrons with a fission spectrum distribution.

INTRODUCTION

Shielding a spallation neutron source is similar in one respect to shielding a fission reactor source but dissimilar in several other important aspects. The Los Alamos Neutron Scattering Center (LANSCE)[1] uses 800-MeV protons from the Clinton P. Anderson Meson Physics Facility (LAMPF)[2] to produce neutrons for basic materials science and physics research.[3] The LANSCE facility is illustrated in Fig. 1. Because it is a spallation neutron source, LANSCE produces neutrons covering about 14 decades in energy (sub-meV to 800 MeV), and experiences shielding problems common to all spallation sources. We discuss the principles of spallation source shielding through a detailed calculation of a geometrically simple shield (an infinite slab), and, using the same example, contrast spallation source spectrum problems with a fission spectrum neutron source.

At Los Alamos, we have a powerful Monte Carlo computational capability applicable to spallation neutron source design.[4] We have used this computational tool for various LANSCE shield designs including: a) proton beam-line shields, b) target shields, and c) neutron beam line and beam stop shields.

Spallation Neutron Source Shielding Issues

High-Energy Neutrons

For spallation reactions, one can take a simplistic view of two types of neutrons being produced: low-energy (< 20 MeV) neutrons and high-energy (> 20 Mev) neutrons. Low-energy neutrons are basically produced in three ways: a) directly from the intranuclear and internuclear cascade processes; b) by evaporation; and c) from fission. These low-energy neutrons are similar in energy to fission neutrons. They are emitted "more-or-less" isotropically and cause shielding problems like those for fission reactors. However, high-energy neutrons, resulting from nucleon-nucleon reactions inside the nucleus, have a strong angular dependence, are difficult to stop, and cause unique shielding problems. At the extreme forward direction to the proton beam (0 degrees) the high-energy neutrons can have energies up to the incident proton energy, which is 800-MeV for LANSCE. As the angle with respect to the proton beam increases, the high-energy neutron spectrum softens considerably. While being attenuated by a shield, high-energy neutrons produce low-energy neutrons, i.e., the shield itself becomes a neutron source. The presence of these high-energy neutrons and their strong angle-dependence are the first two reasons why shielding a spallation source is quite different than shielding a reactor source.

Thin and Thick Targets

Consider the LANSCE proton beam line, and imagine first that the LANSCE 800-MeV proton beam strikes the proton beam pipe. Secondly, ponder the case when the proton beam strikes a magnet in the proton beam line. These two scenarios present different neutron spectra (dissimilar in both intensity and energy) to a shield adjacent to the spill location. Because of this disparity in incident spectra, the effectiveness of a shield could be significantly different in the two cases. Let us look at a few examples.

For 800-MeV protons incident on stainless steel (a typical LANSCE beam line and beam pipe material), the calculated double differential (energy and angle) neutron production cross sections are illustrated in Fig. 2. The angle bins around the quoted angles are as follows: a) 5 degrees (0-10 degrees), b) 175 degrees (170-180 degrees), and c) all other angle bins are + 5 degrees about the stated angle. This cross section calculation represents the neutron production from an infinitely thin target (one atom thick). One can see the strong angular dependence of the high-energy component. The Low-energy neutrons are 'nearly' isotropic; in Fig. 2, we show the average low-energy spectrum over 4π. The ratio of high- to low-energy neutrons varies with angle.

For a 'thick target', the ratio of high- to low-energy neutrons, and the shape and magnitude of the leakage neutron spectra can change dramatically from one target to another; the target itself 'moderates' and 'self-shields' the neutrons it produces. The neutron spectrum from a mild steel thick-target (50 cm thick and 20 cm in diameter) bombarded by 800-MeV protons is shown in Fig. 3. This spectrum is integrated over all angles. Mild steel is a typical magnet material in the LANSCE proton beam line. In Fig. 3, we also show the equivalent spectrum from a thin-target (0.3 cm thick and 20 cm in diameter) of the same material. The dramatic difference (both in intensity and energy) between the two leakage spectra is evident. In Fig. 3, we also show the neutron spectrum from a 30-cm-long and 10-cm-diameter tungsten target bombarded by 800-μeV protons. This is the type of neutron production target used in the LANSCE facility.

We have now accounted for a third reason why shielding a spallation source is more complex than shielding a reactor source: different leakage neutron spectrum are produced depending upon whether the proton beam strikes a thin or thick target; neutron production is also material c endent. There is a fourth complicating factor.

Thin and Thick Shields

When talking about a neutron shield for a spallation source, one must differentiate between 'thin' and 'thick' shields. In a particular shielding application, this distinction can be important and may affect the applicability of simplistic formalisms for estimating the neutron doses at the shield surface. Depending on whether the shield is thin or thick will determine if the primary evaporation neutron component (that component produced directly by the target) incident on the shield will contribute significantly to the neutron dose at the shield surface.

We define a thin shield to be one where the primary evaporation neutrons contribute significantly to the neutron dose at the outer shield surface. Conversely, for a thick shield, the primary evaporation neutrons do not contribute meaningfully to the neutron dose at the outer shield surface. Primary evaporation neutrons are only one of three components contributing to the neutron dose. The other two components are: a) high-energy neutrons, and b) secondary evaporation neutrons produced by high-energy neutron interactions in the shield itself. These secondary low-energy neutrons are distributed throughout the shield, and arise from the disappearance (attenuation) of the high-energy neutrons as they 'penetrate' the shield.

This is the fourth complexity arising in shielding a spallation source relative to a reactor source: the shield itself is a source of low-energy neutrons. For a spallation neutron source shield application, the effects of primary and secondary low-energy neutrons can be accounted for explicitly or by attenuating the high-energy neutrons with an 'effective' cross section or mean-free-path. There are three more differences between shielding a spallation source relative to a reactor source.

Neutron Flux-To-Dose Conversion Factors

The fifth difference has to do with the flux-to-dose conversion factors for neutrons. This effect deals with neutron flux required to produce one mrem per hour of dose. It is an energy dependent phenomenon and is shown in Fig. 4.[5] As can be seen, it takes a flux of about 5.5 n/cm**2-s of 100 MeV neutrons to produce 1 mrem/hr of dose, compared to a flux of about 220 n/cm**2-s of 1 eV neutrons. Therefore, the energies of the neutrons leaking through the shield can have profound effects on the dose at the shield surface.

Neutron Flux Versus Neutron Dose Attenuation

The sixth difference between spallation and reactor source shielding has to do with how neutrons are attenuated. We now have to talk about neutron flux and dose attenuation; both are important in overall LANSCE shielding concerns. Neutron and gamma-ray flux are related to the physical number of neutrons and photons, respectively. Detectors used in LANSCE scientific instruments respond to flux. However, these detectors are inside the instrument shielding; the response of such a detector must include the effects the instrument shield has on the incident neutrons and gamma-rays. Dose, on the other hand, is related to human biological issues. We need to have unlimited human access to the LANSCE experimental areas while LANSCE is operating; therefore, dose is also a relevant issue.

Flux and dose are attenuated differently by a shield. This is primarily due to the energy dependence of the flux-to-dose conversion factors (see Fig. 4). For example, when you 'attenuate' a low-energy neutron dose, you are doing two things: a) moderating (slowing down) the neutrons within the shield, thereby decreasing the neutron dose, and b) capturing neutrons and producing gamma-rays. Whether attenuation of flux or dose dominates the criteria for a shield design depends on the particular shield application. Flux is important when shielding detectors; dose is important when shielding people.

Gamma-Rays

From a biological viewpoint, we need to concern ourselves with the total dose (neutron plus gamma-rays) at the outside of a shield, and not just the neutron dose. Detectors also respond to gamma-rays (some are more sensitive than others). You cannot arbitrarily neglect gamma-rays when designing detector shielding. All low-energy neutrons which do not undergo particle reactions such as (n,), (n,p), etc. with nuclei are eventually captured in the shield or leak from it. In addition to normal capture and inelastic scattering gamma-rays from low-energy neutron interactions, the 'spallation' process produces additional gamma-rays which may or may not be important in a particular shield application.

Thus, we have identified the seventh (and last) difference between spallation and fission source shielding to be an additional gamma-ray source from the 'spallation' process itself. Depending on the application, one may need to account for all three neutron components (primary low-energy, high-energy, and secondary low-energy) plus gamma-rays when designing a shield for a spallation neutron source.

Biasing the High-Energy Neutron Source

Another complication in using calculated high-energy neutron spectra in shield design is the potential that the computed angle-dependent spectra are incorrect both in magnitude and shape compared to measured results.[6] This is a complex issue; Los Alamos has been a major player in the measurement and calculation intercomparison arena.[7] Qualitatively (depending on the measurement), there has been both excellent agreement and up to a factor of five disagreement between measured and calculated double-differential high-energy neutron production; generally, calculations underpredict measured values. Until these problems are resolved, one may (in some shield calculations) appropriately 'bias' the calculated high-energy neutron production by some factor to account for these uncertainties. Such a bias may be consequential when deciding the relative importance between primary and secondary low-energy neutrons in a particular shield design.

LANSCE SHIELDING CONCERNS

Before we discuss neutron flux and dose, we should talk about the LANSCE shielding issues; they can be broadly categorized as follows:

- o shield source-terms;
- o proton beam line shielding;
- o service cell shielding;
- o target/moderator/reflector shielding;
- o 'bulk' shielding;
- o neutron collimator design;
- o longitudinal neutron beam line shielding;
- o transverse neutron beam line shielding;

o neutron instrument shielding;

o neutron beam stop shielding.

We have addressed many of these shielding concerns in other calculations.[8--?]

CALCULATIONS FOR AN INFINITE IRON/POLYETHYLENE SLAB-SHIELD

Problem Definition
To help understand the complexities of spallation source shielding, we deliberately chose a geometrically simple shield to calculate (an infinite slab). The shield (see Fig. 5) was composed of 100 cm of iron (mild steel) followed by 15 cm of borated polyethylene (5% natural boron) with a monodirectional point source of neutrons incident normal to the iron shield surface. A unit source of spallation neutrons calculated at 90 degrees (+ 5 degrees) to the 30-cm-long by 10-cm-diameter tungsten was used as the 'spallation' spectrum and is shown in Fig. 6. In addition, we also used a unit watt fission spectrum, which is also depicted in Fig. 6.

Results
Calculated neutron and gamma-ray fluxes throughout the shield and at the shield surfaces are shown in Fig. 7.

Calculated neutron and gamma-ray doses throughout the shield and at the shield surfaces are given in Fig. 8.

The secondary low-energy neutron production througout the shield and the corresponding neutron fluxes and doses are depicted in Fig. 9.

The effects of a unit primary low-energy spectrum and a unit Watt fission spectrum on neutron and gamma-ray fluxes and doses are shown in Fig. 10.

CONCLUSIONS

A spallation neutron source presents different shielding problems than those posed by a reactor source The seven differences are as follows:

- the presence of high-energy (> 20 Mev) neutrons;

- a strong angular dependence of the high-energy neutrons;

- different leakage neutron spectra are produced depending upon whether the proton beam strikes a thin or thick target;

- the shield itself is a source of low-energy neutrons;

- neutron and gamma-ray flux-to-dose conversion factors have a strong energy dependence;

- neutron flux and dose are attenuated differently in a spallation neutron source shield than a reactor source shield;

- there is an additional source of gamma-rays resulting from the 'spallation' process itself.

Whether high-energy (> 20 MeV) or low-energy (< 20 MeV) neutrons dominate the neutron dose at the surface of a shield, depends on the incident neutron spectrum and the shield composition and thickness.

A unit Watt fission spectrum causes worse shield problems than a unit low-energy evaporation spectrum for the test shield, even though the evaporation spectrum is harder.

We will use the Los Alamos HETC/MCNP Monte Carlo Code System for particular LANSCE shield problems, and to evolve 'rules-of-thumb' for 'back-of-the-envelope' LANSCE shield calculations.

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6. D. Filges ---

7. M. M. Meier ---

8. G. J. Russell, Technical notes ---

<u>Figures</u>

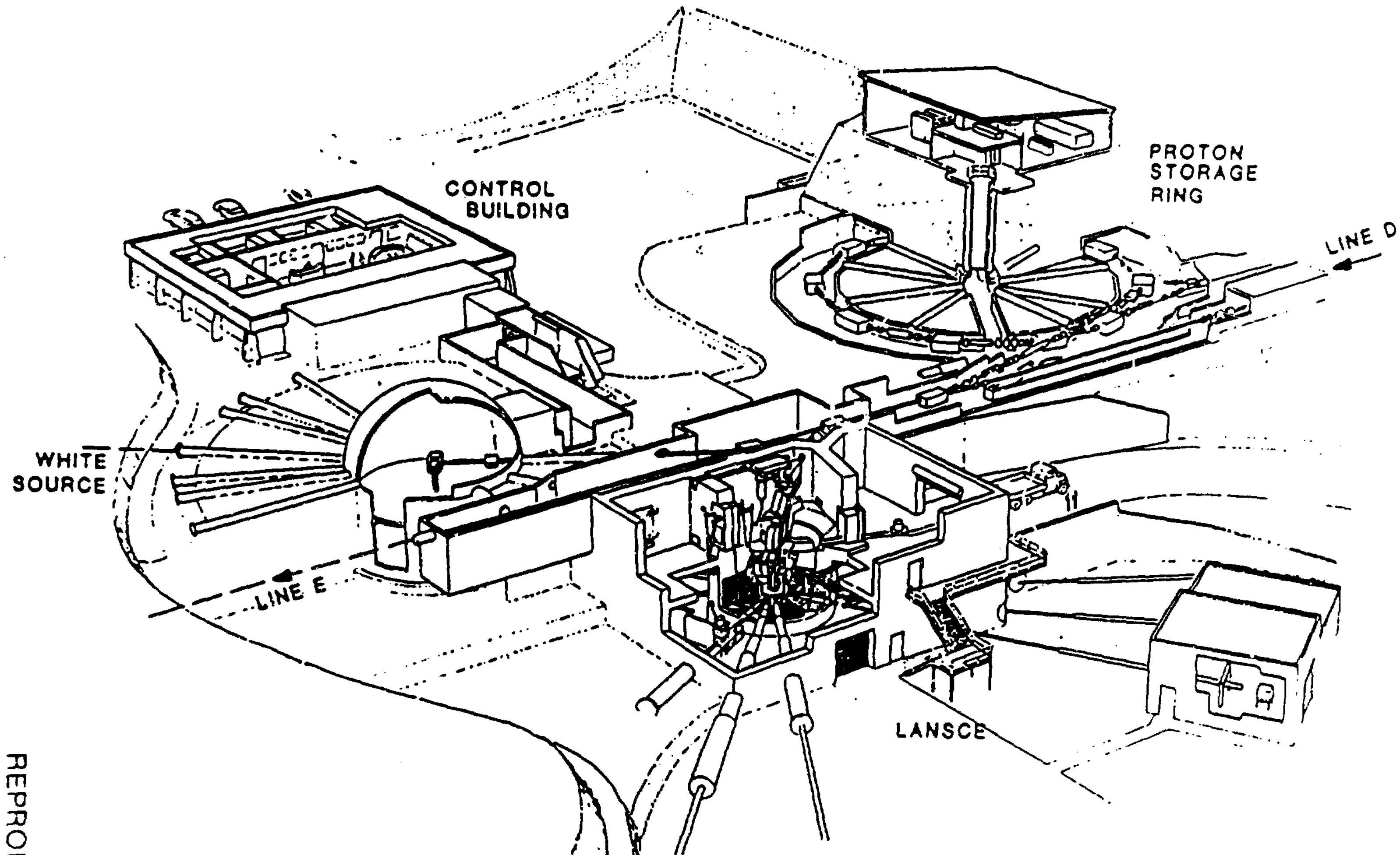
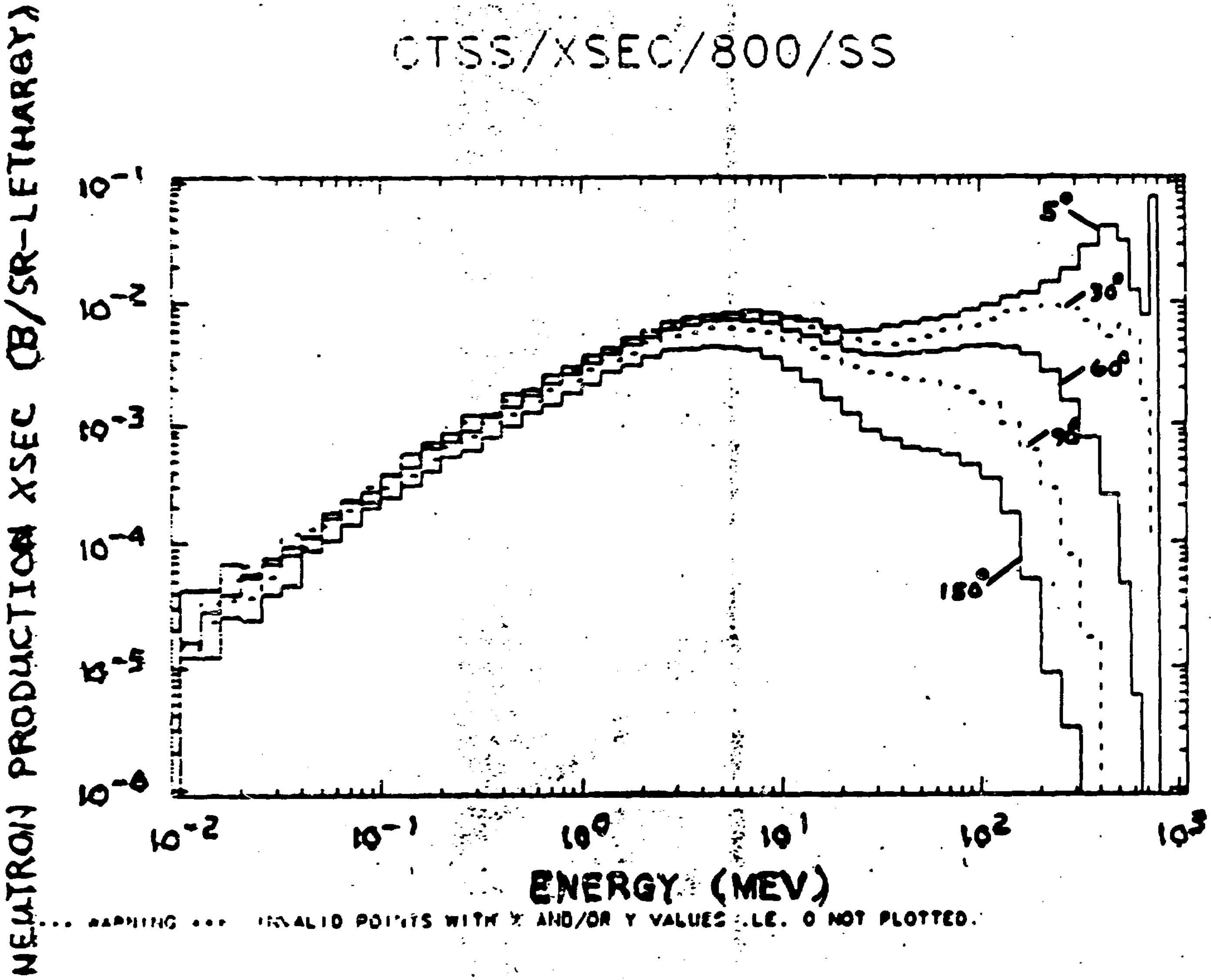
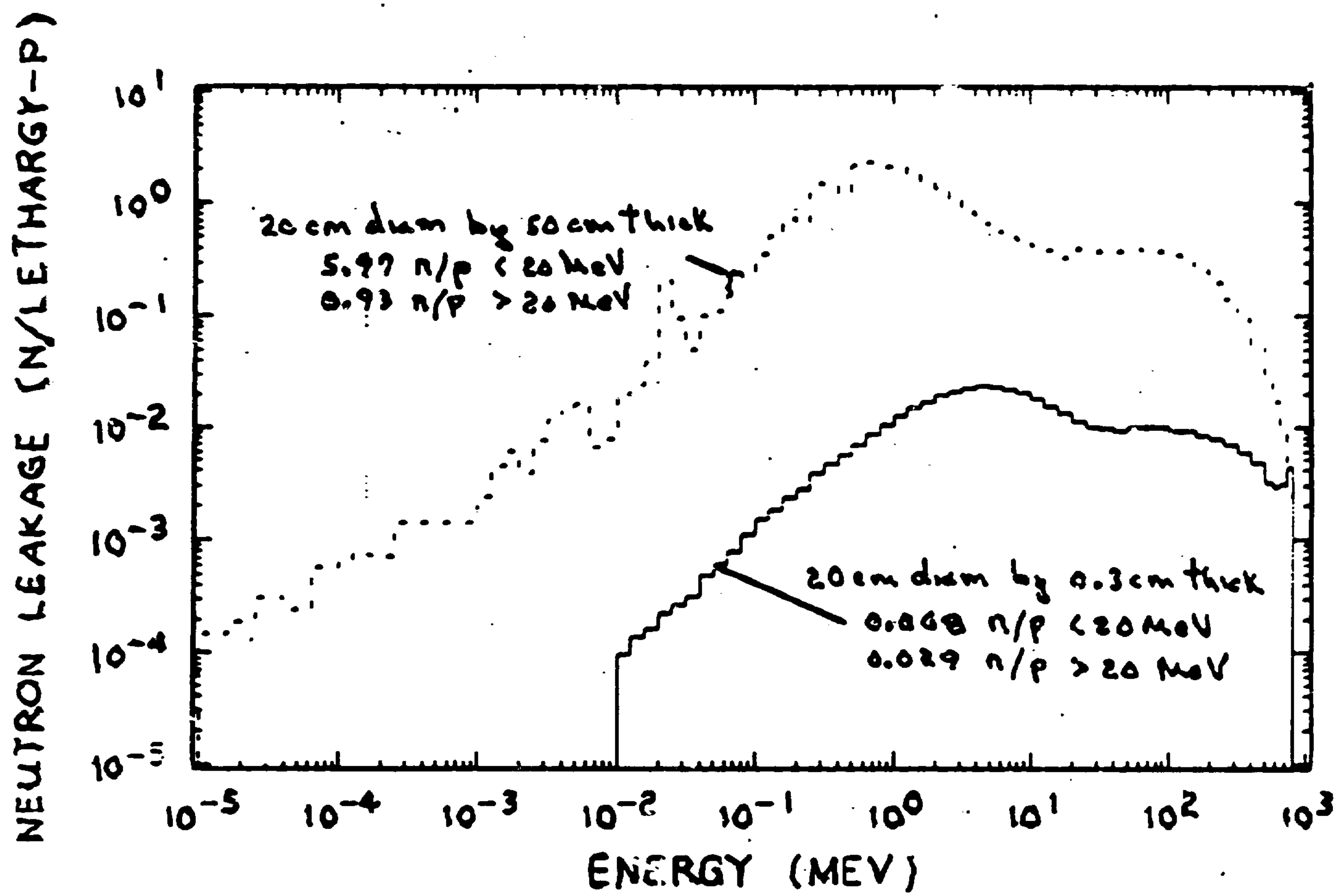
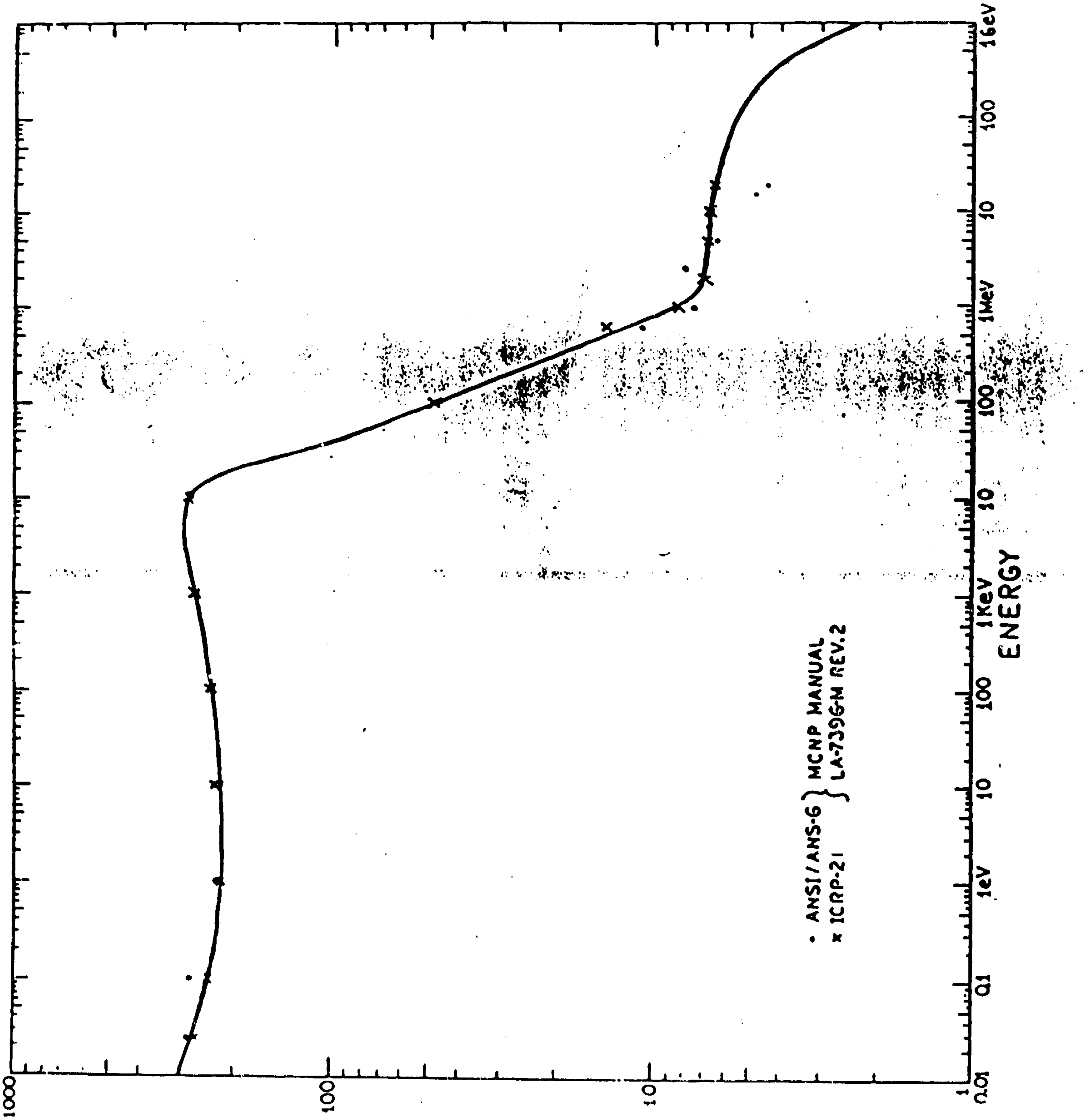


Fig. 1. General layout of the LANSCE/WNR complex. The new Neutron Scattering Experimental Hall, under construction in 1987, will surround the present LANSCE experimental hall (shown in the foreground) and will greatly enhance the LANSCE experimental area.


CTSS/XSEC/800/SS
NEUTRON PRODUCTION XSEC (B/SR-LETHARGY)
ENERGY (MEV)
5°
30°
60°
90°
180°
... WARNING ... INVALID POINTS WITH X AND/OR Y VALUES .LE. 0 NOT PLOTTED.

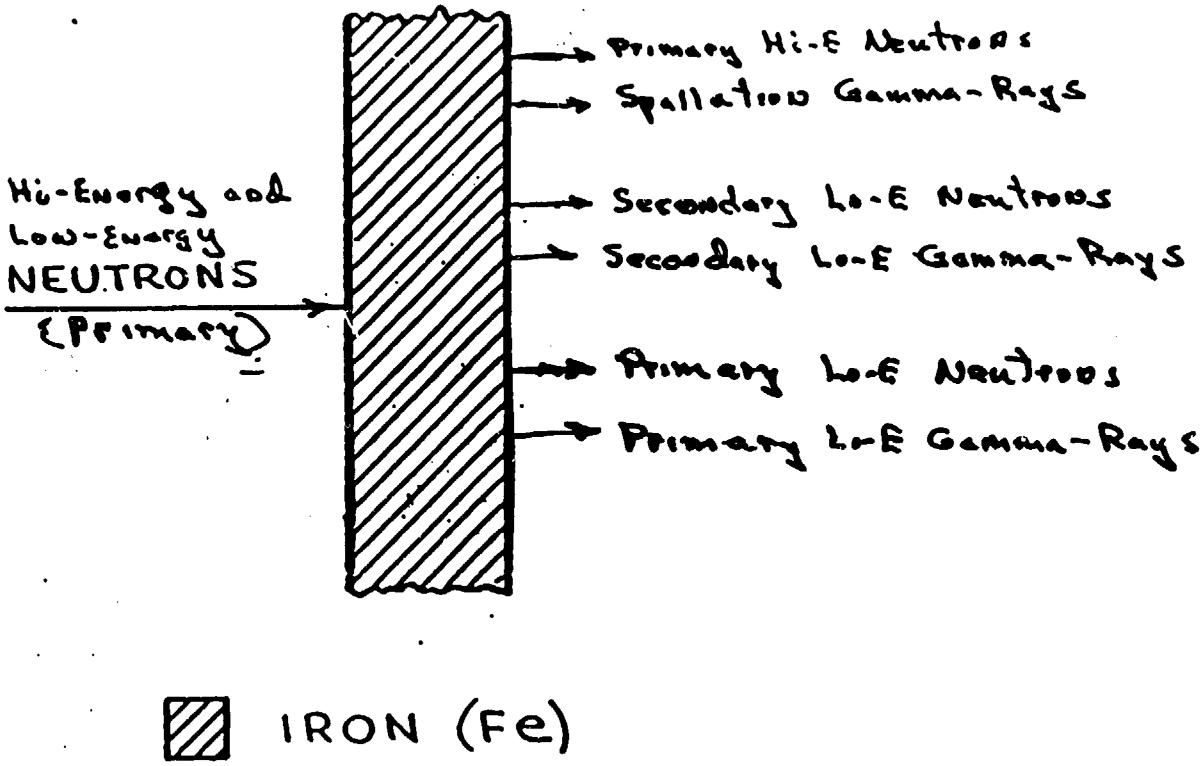
SHIELD/SOURCES/SUM/INPCH1





• ANSI/ANS-6
× ICRP-21
MCNP MANUAL
LA-7396-M REV.2
ENERGY
0.01
0.1
1eV
10
100
1KeV
10
100
1MeV
10
100
1GeV
1000
100
10
1.0

Fig. 4.



Note: Outer constituent of shield is important

Fig. 5.

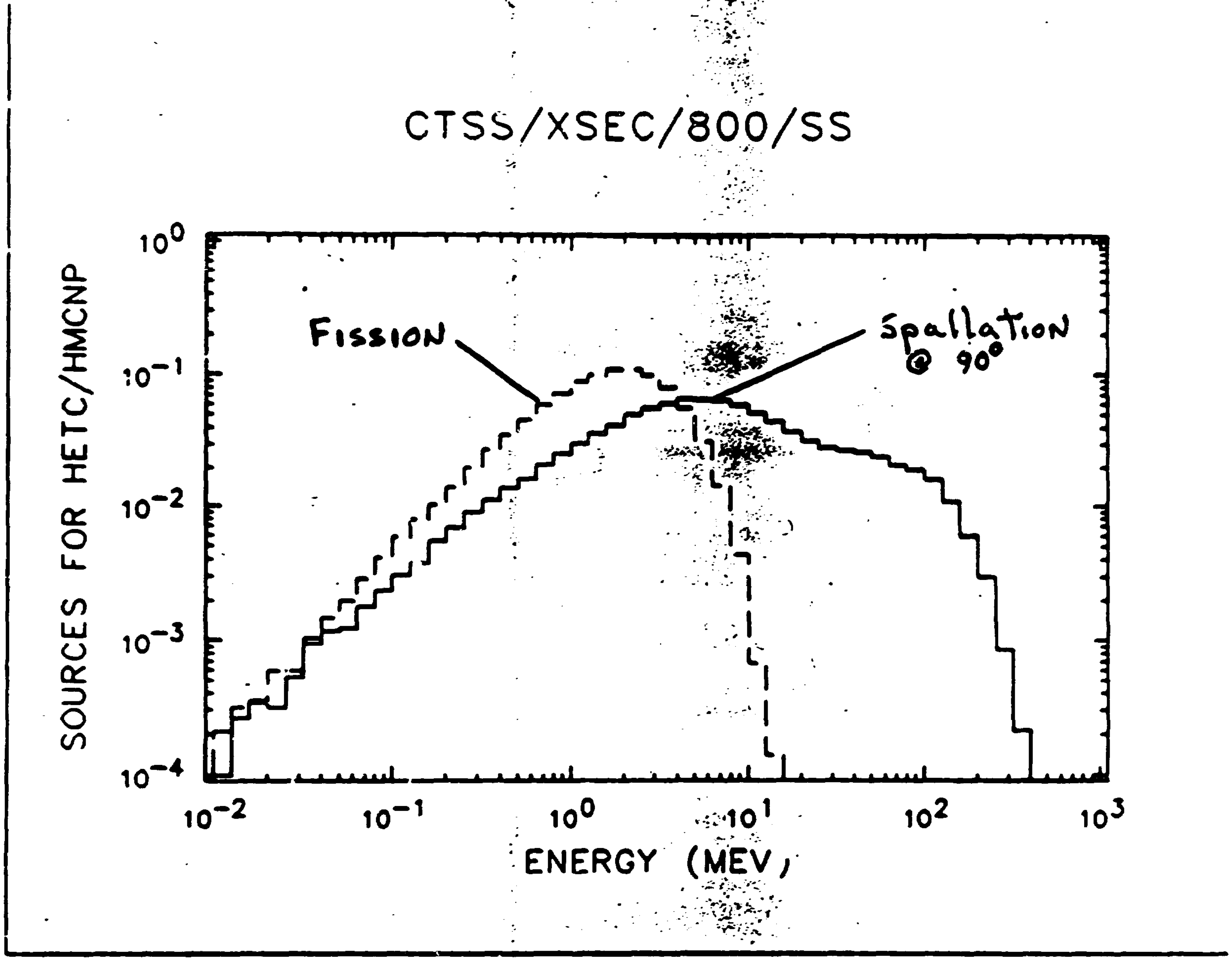
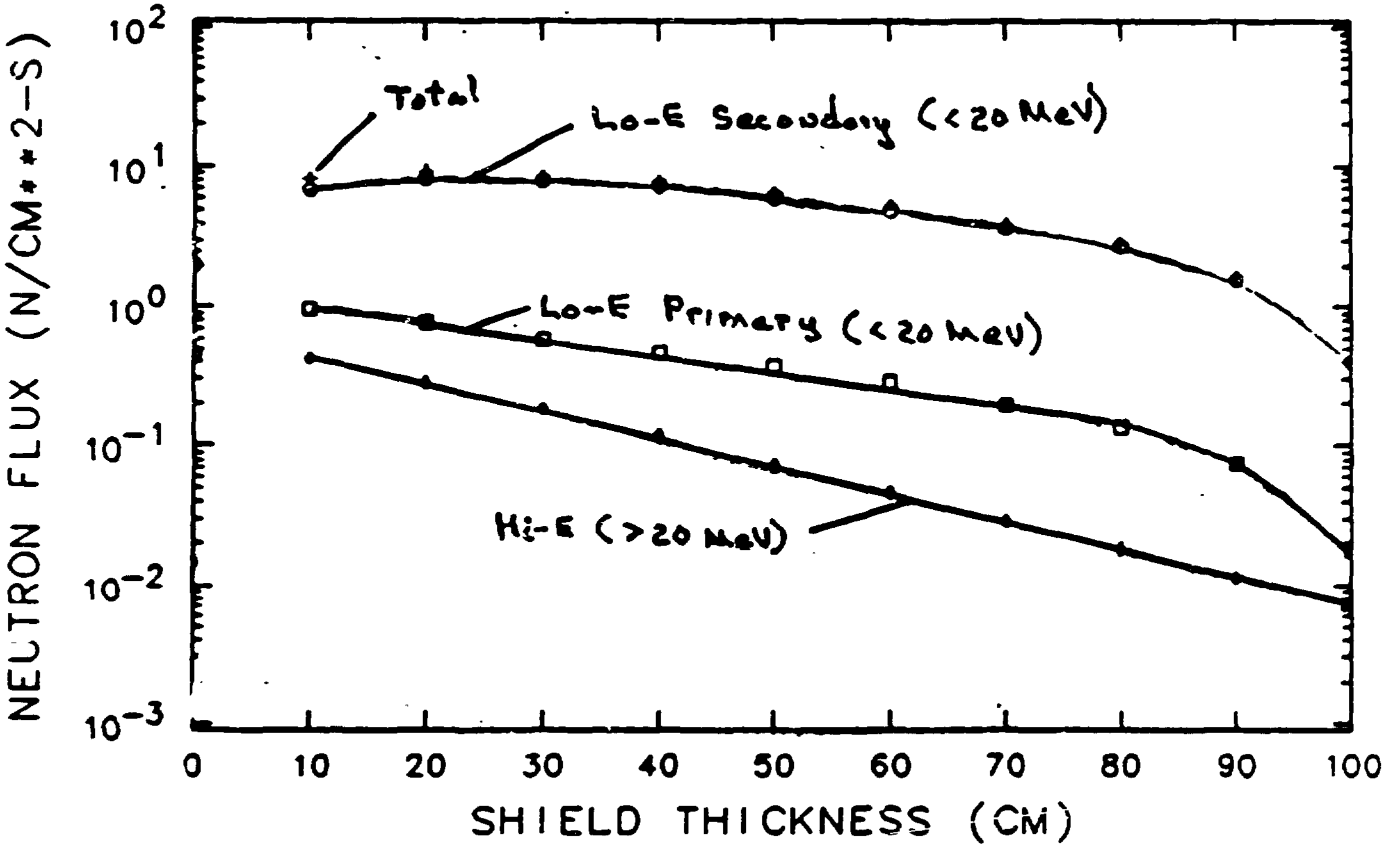

CTSS/XSEC/800/SS
SOURCES FOR HETC/HMCNP
ENERGY (MEV)
Fission
Spallation @ 90°
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Fig. 6

0-10 DEGREE NEUTRONS FROM CTSS/XSEC/800/SS
& Gamma-Rays



Note

Dose would Attenuate Differently

Fig. 2.

SHIELD/4/INPD1
UNNORMALIZED

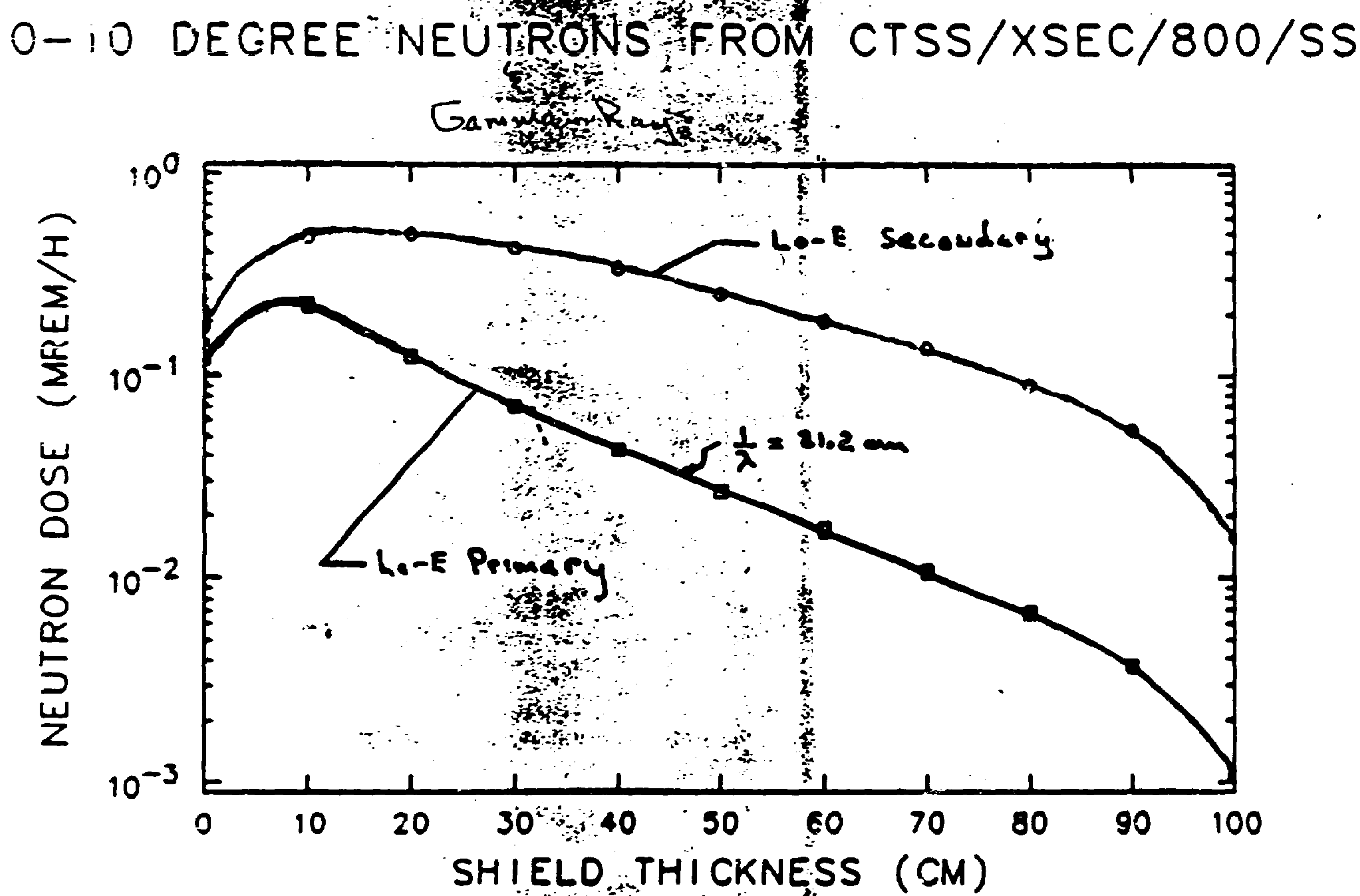


Fig. 5

0–10 DEGREE NEUTRONS FROM CTSS/XSEC/800/SS

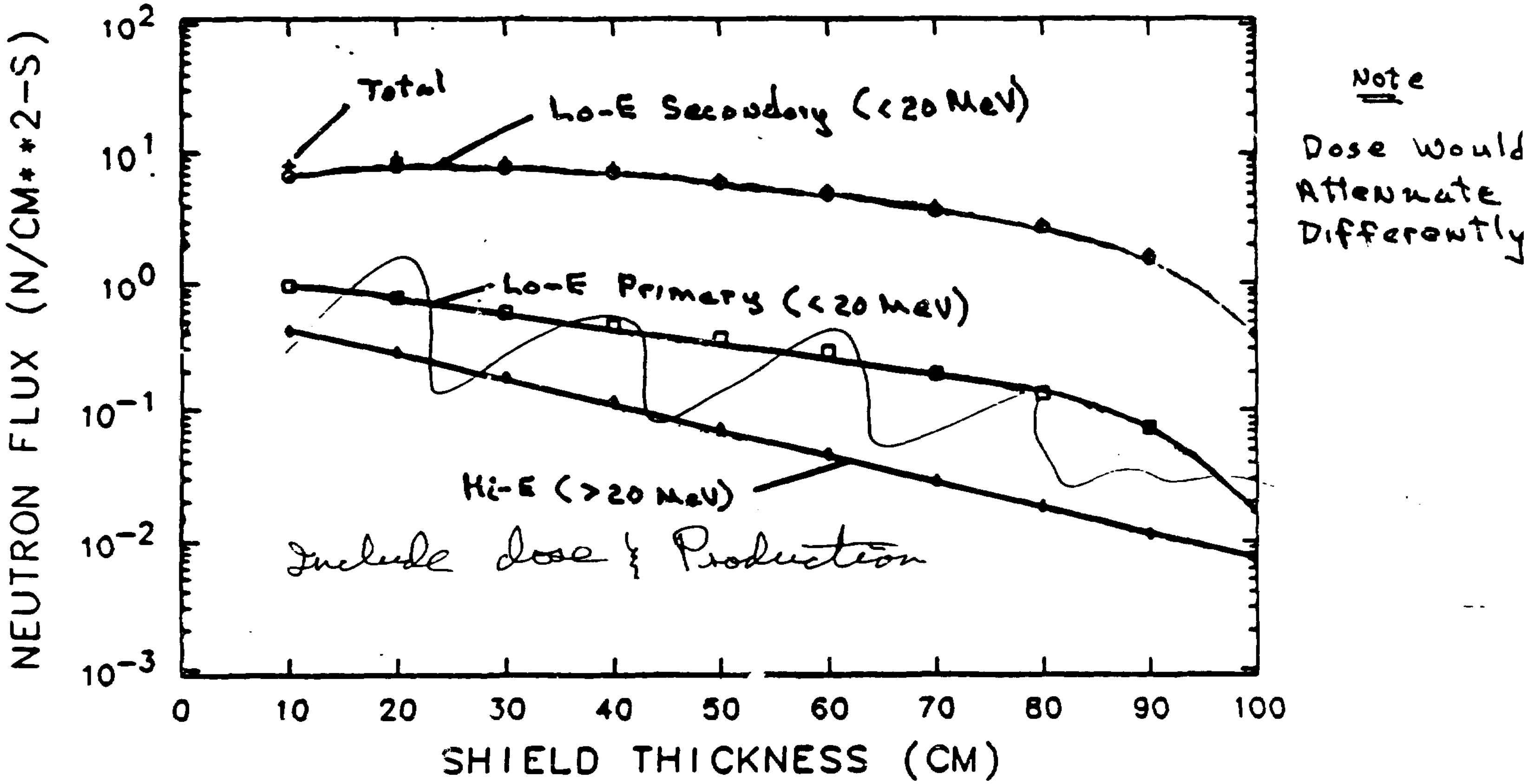


Fig. 9

BEAMSTOP/5/INPCC1

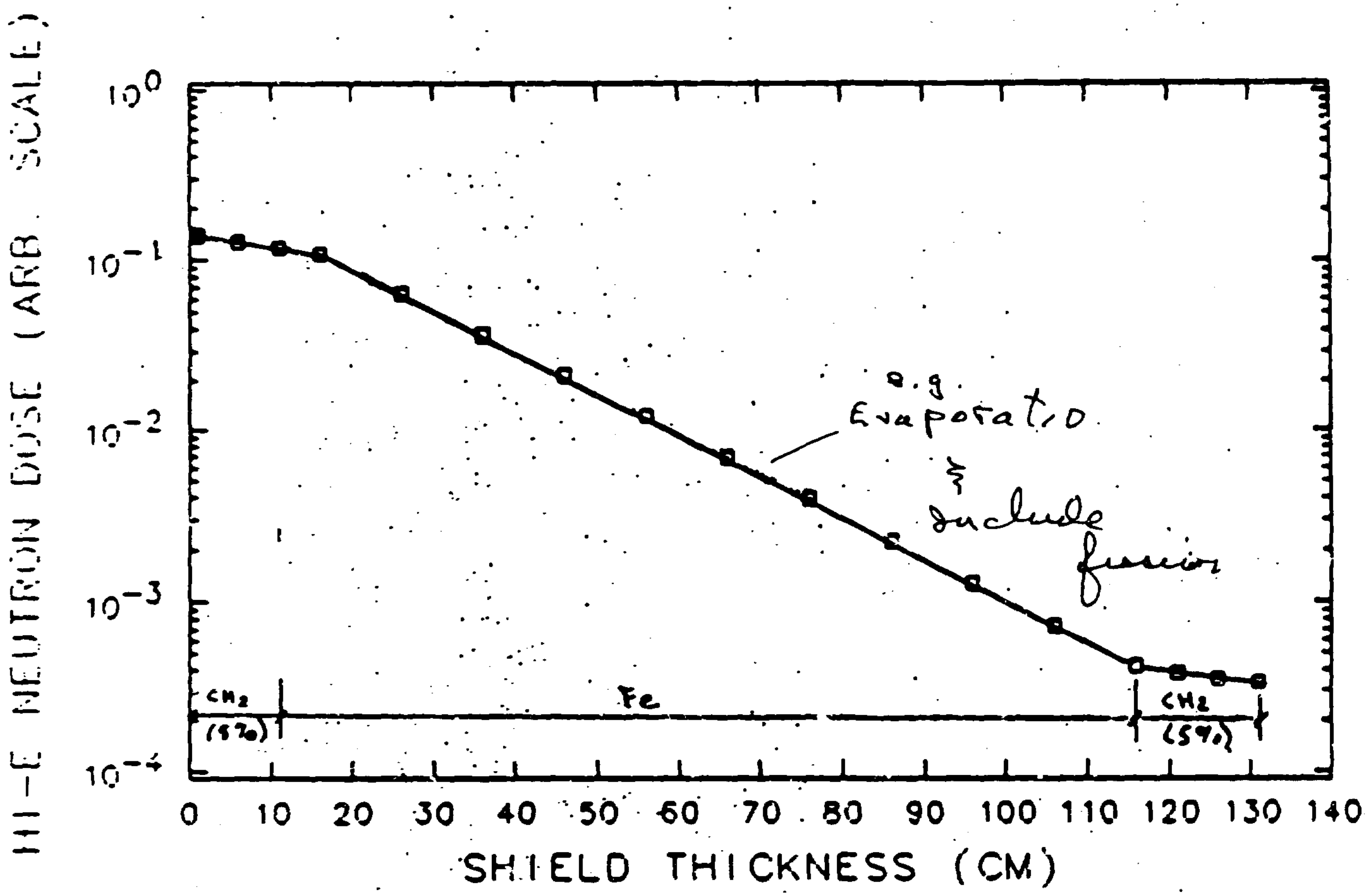


Fig. 1.6