High Gain Target Spectra and Energy Partitioning for Ion Beam Fusion Reactor Design Studies

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Introduction

This report contains reproductions of the figures used in our 1980 APS Plasma Physics Meeting poster paper 9R19. Each figure is accompanied by a brief explanation of its content. In the future we expect to publish a more comprehensive study of target spectra from such ion beam targets.

The purpose of this poster paper is to estimate the output spectra and partitioning of energy for ion beam fusion targets. Since our purpose is not to design ICF targets, we have chosen a target that is reported in the literature(1) as representative of ion beam target designs. We believe that the general features of the output spectra will be similar for any similar target design. This particular design was reported to have the following characteristics:

Ion Type	Proton
Ion Energy	6.5 MeV
Ion Beam Energy	1.3 MJ
Target Yield	113
Target Gain	88

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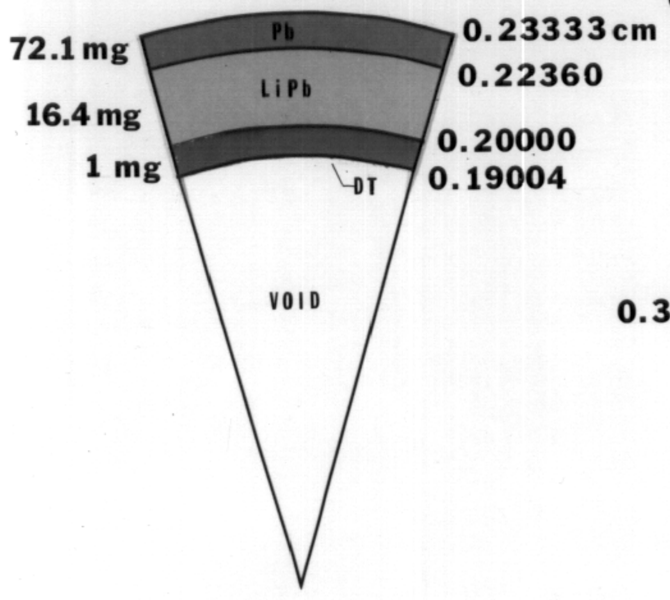
(1) R. Bangerter and D. Meeker, Lawrence Livermore Laboratory Report UCRL-78474 (1976).

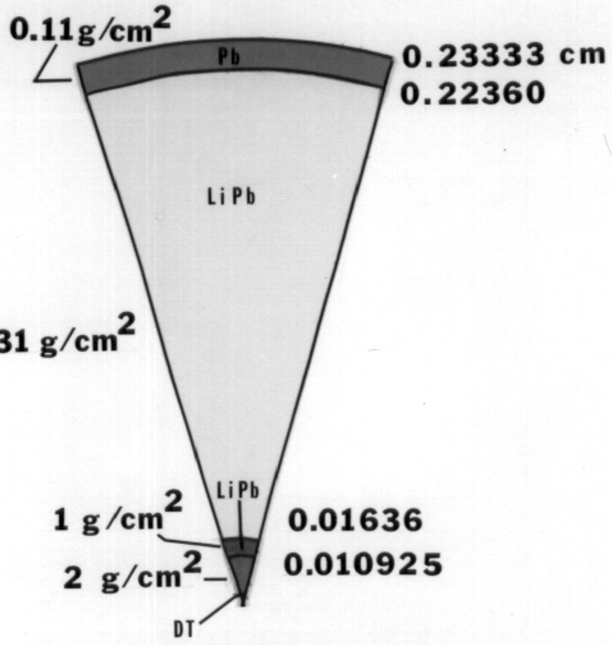
Target Configuration

The initial target configuration is shown on the left of the figure. It consists of a DT layer frozen onto the inside of a PbLi low density layer which is surrounded by a high density Pb shell. The high Z impregnated plastic, TaCOH, of ref. 1 has been replaced with a PbLi mixture of the same density, 1.26 g/cm^3. With this altered design, the only non-condensable target materials are D, T, and the He fusion reaction product. The DT is levitated to an aspect ratio of 20. The low density pusher is less susceptible to fluid instabilities at the fuel-pusher interface than a high density pusher would be. This is because the Atwood number is lower. The outer two shells (Pb and PbLi) are designed such that the distinctive Bragg peak in the proton energy deposition curve falls in the PbLi layer, near its interface with the Pb shell. Consequently, little beam energy is deposited in the Pb and it serves as an inertial tamper with very little decompression during the implosion.

The postulated target configuration at ignition is shown on the right. This is estimated from information in ref. 1 rather than from our own hydrodynamics simulation. We estimate that the combined fuel-pusher ρR value is 3 g/cm^2. This will give approximately the same yield as reported in ref. 1.



**INITIAL
CONFIGURATION**



**IGNITION
CONFIGURATION**

Energy Partitioning

The results of our calculations have been normalized to exactly 100 MJ of DT fusion yield to simplify the analysis. This yield is partitioned as shown in the table. Note that only 71%, and not 80%, of the energy emerges in the form of neutrons. The endoergic (n,2n) and (n,3n) reactions between fusion neutrons and the target material account for a net loss of 1.6 MJ of energy but the total number of neutrons is increased by about 5%. The Li in the target produces a tritium breeding ratio of 1%. Gamma ray emission from neutron reactions accounts for 0.15 MJ of energy. This is included in the neutron yield in the table.

ION BEAM TARGET YIELD

TOTAL FUSION YIELD	100 MJ
NEUTRON YIELD	71 MJ
X-RAY YIELD	20 MJ
ION YIELD	7.4 MJ
ENDOERGIC REACTIONS	1.6 MJ
NEUTRON MULTIPLICATION	1.046
AVERAGE NEUTRON ENERGY	12 MeV
AVERAGE GAMMA ENERGY	1.53 MeV
TRITIUM BREEDING RATIO	0.01
X-RAY SPECTRUM	~1 keV b.b.

Neutron Spectrum

The opposite figure shows the spectrum of neutrons escaping from the target. The majority of neutrons escape at 14.1 MeV but 29% of them suffer a collision. The two small peaks in the continuum are due to elastic back-scattering from deuterium and tritium.

The calculation was performed using the ANISN(2) discrete ordinates transport computer code with the University of Wisconsin 25 neutron-21 gamma group cross section library. The target configuration was that shown in the previous figure.

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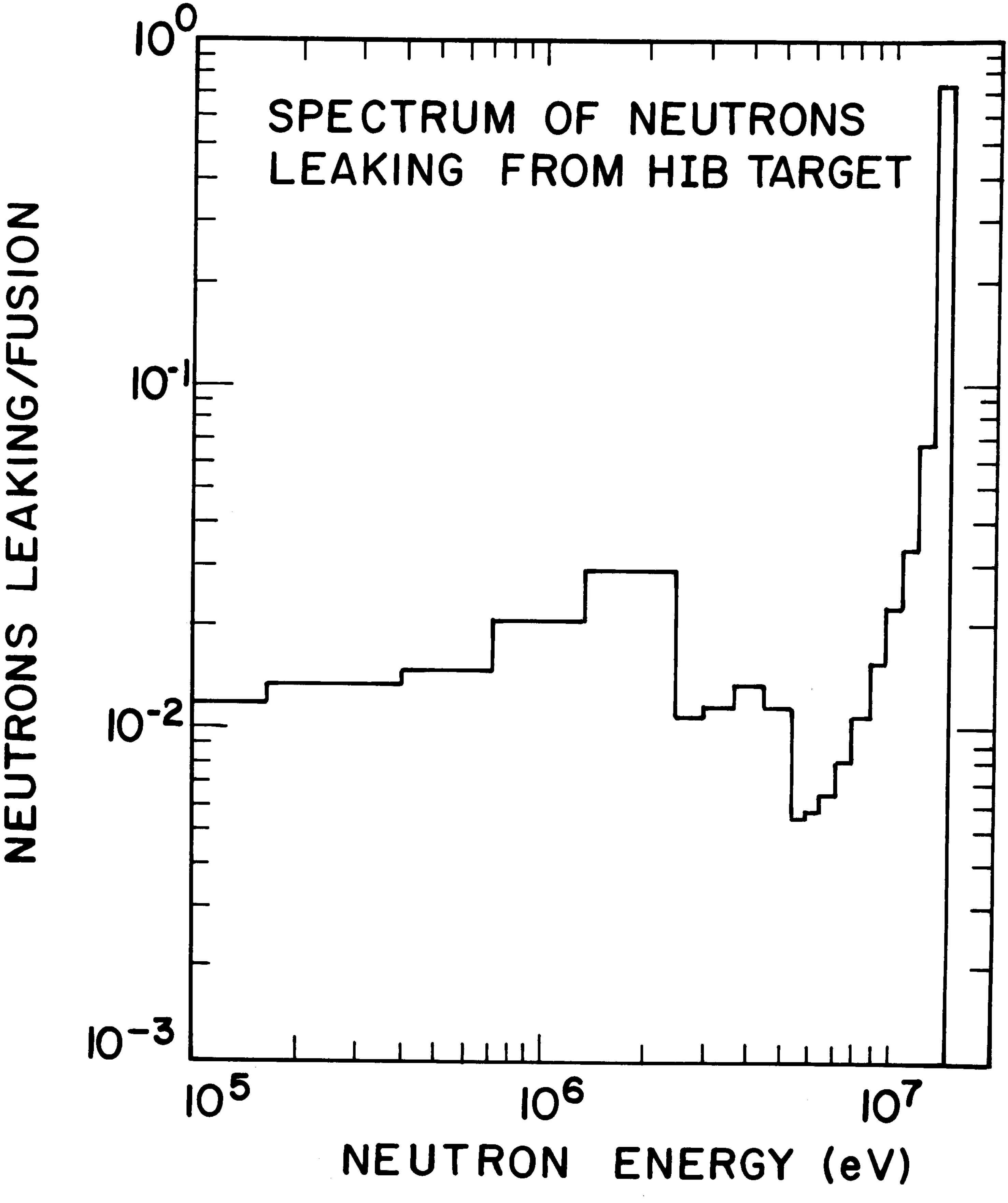
(2) W. Engle, Oak Ridge National Laboratory Report K-1693 (March, 1967).


SPECTRUM OF NEUTRONS LEAKING FROM HIB TARGET
NEUTRONS LEAKING/FUSION
10^0
10^{-1}
10^{-2}
10^{-3}
10^5
10^6
10^7
NEUTRON ENERGY (eV)

Target Material Activation

The activation of target materials and their subsequent decay are shown in the opposite figure. The very high initial activity of 10^5 curies is due to the $^6Li(n,p)^6He$ and $^7Li(n,\gamma)^8Li$ reactions. The ^6He and ^8Li have 800 msec half-lives and consequently this activity decays very rapidly, in about one minute. The mid-term activity is due to ^{205}Hg and ^{203}Pb with half-lives of 5.5 minutes and 52 hours respectively. The long term activity is from ^{205}Pb with a 3 x 10^7 year half-life.

These calculations assume pure materials without any isotopic tailoring from the natural isotopic fractions.

The calculations were performed with the DKR radioactivity code(3) using neutron fluxes from ANISN.

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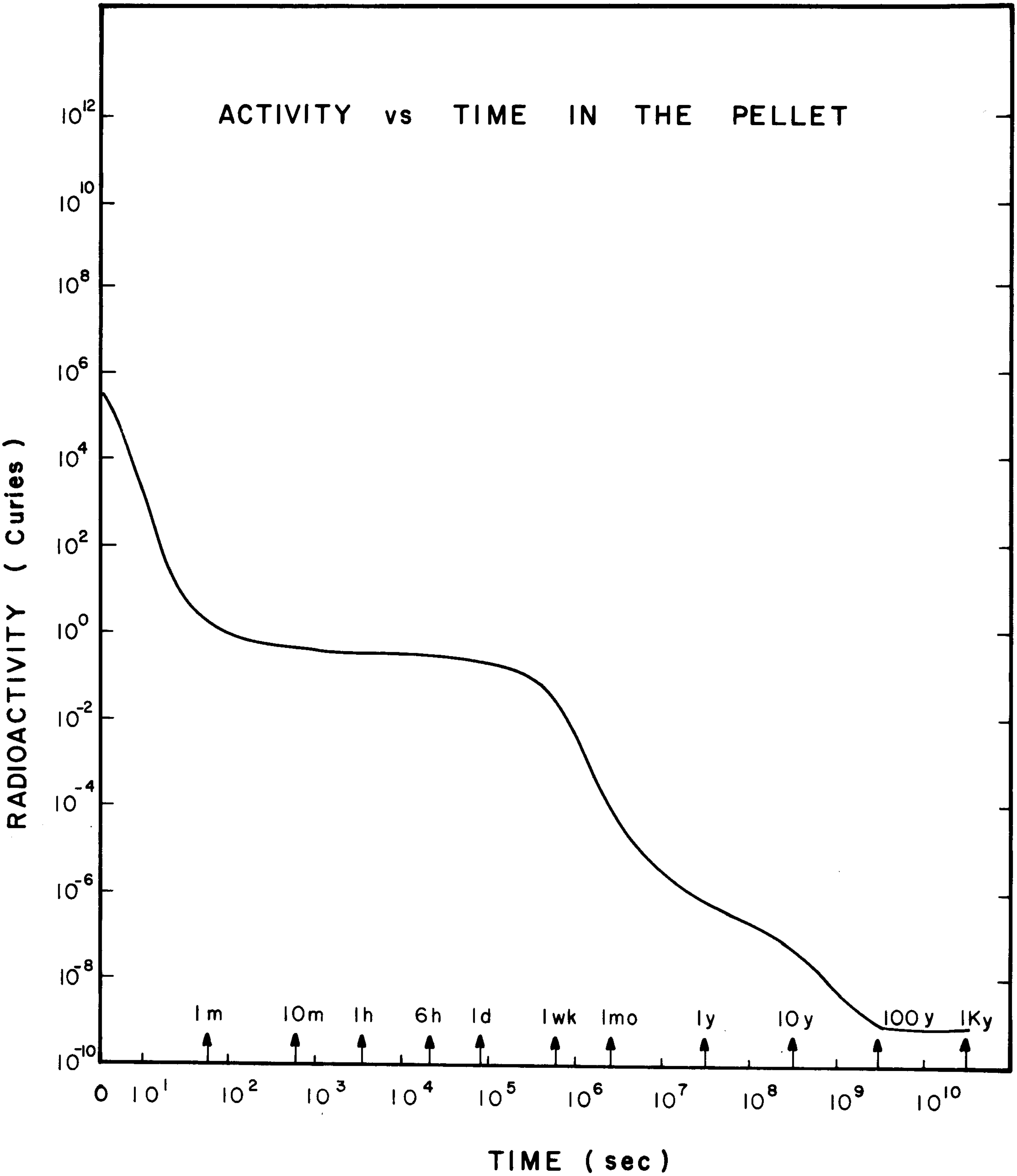
(3) T. Sung and W. Vogelsang, University of Wisconsin Fusion Engineering Program Report UWFDM-170 (1976).

ACTIVITY vs TIME IN THE PELLET
RADIOACTIVITY (Curies)
TIME (sec)
10^12
10^10
10^8
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
10^-8
10^-10
0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
1m
10m
1h
6h
1d
1wk
1mo
1y
10y
100y
1Ky

X-Ray Spectrum at 3.5 nsec

The time integrated x-ray spectrum at 3.5 nsec following ignition is shown in the figure. It is characterized by two peaks with the lower energy "thermal" part approximated by a 1 keV blackbody. Hard x-rays generated in the burning DT fuel are partially attenuated by the surrounding tamper material. Those x-rays with energies higher than the K-edge of the high Z tamper material escape (the small peak at 100 keV). The attenuated x-rays, along with neutrons and ions, heats the tamper material to a temperature of about 1 keV and this leads to the thermal part of the spectrum.

The x-ray and ion spectra were computed using the PHD-IV Lagrangian hydrodynamics code.(4) An 11 group multifrequency variable Eddington treatment of radiative transfer was used to obtain the x-ray spectrum. Equations of state and opacity data for PbLi and Pb were not available so those for Ne and Fe were substituted. For this particular calculation this should not drastically affect the results.

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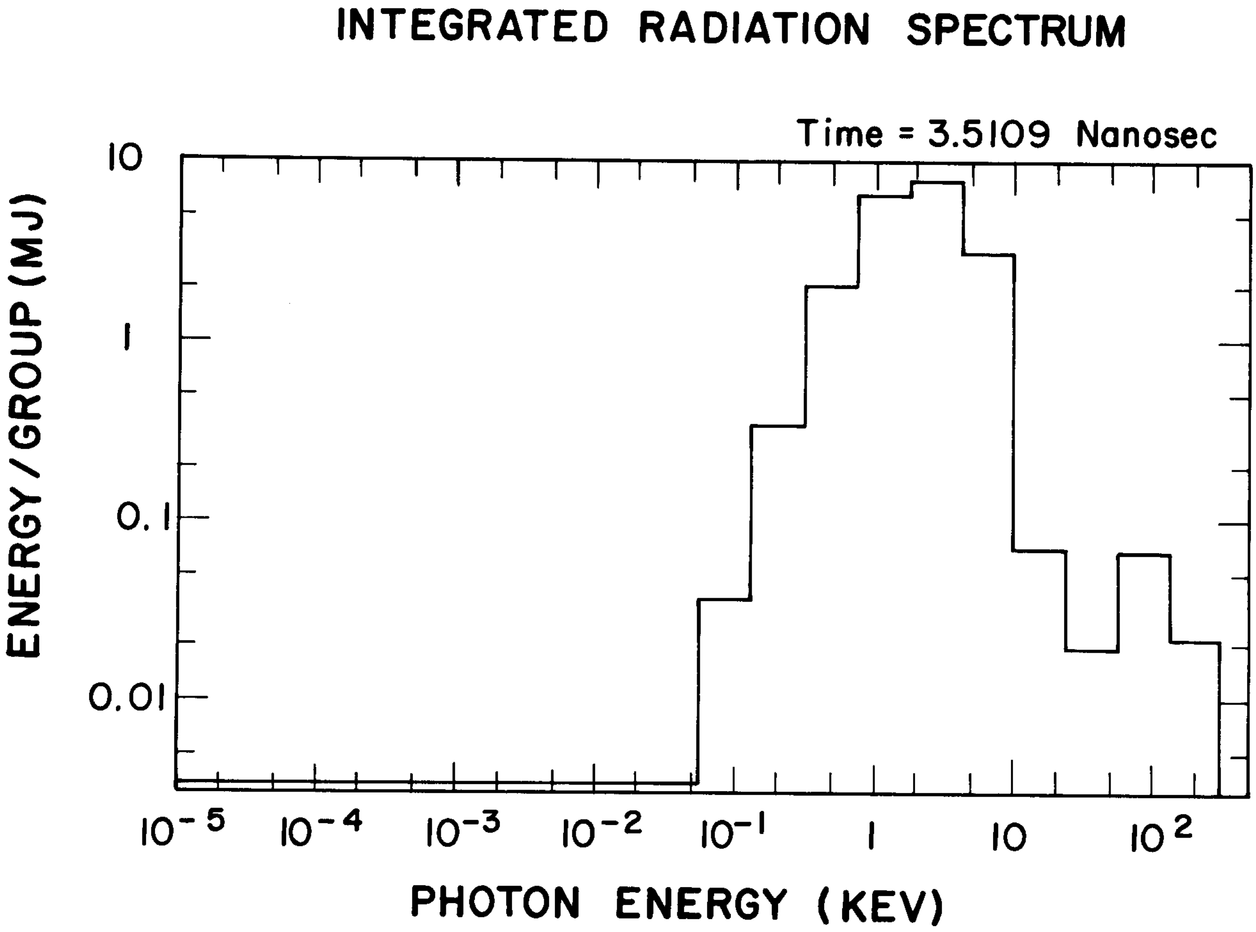
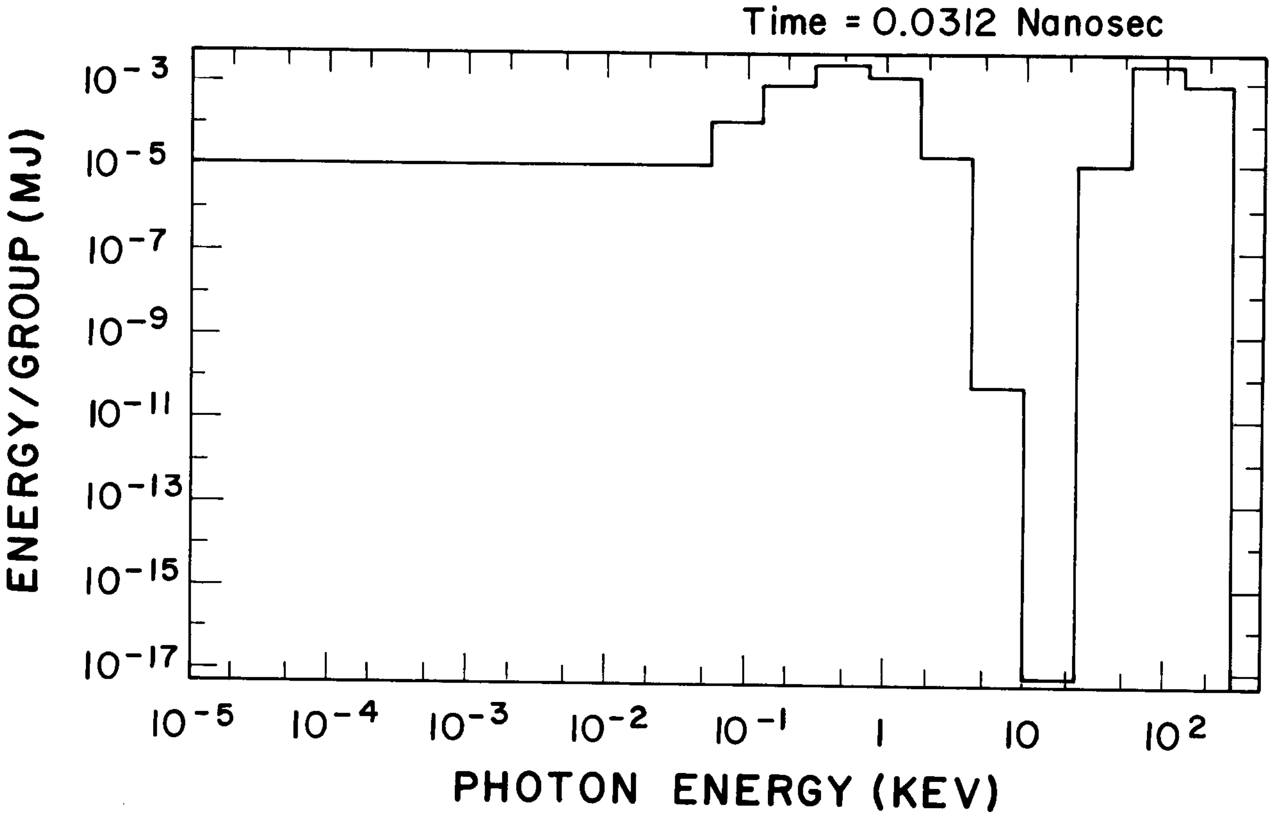
(4) G. Moses and G. Magelssen, Trans. ANS 27, 39 (1977).


INTEGRATED RADIATION SPECTRUM
Time = 3.5109 Nanosec
ENERGY/GROUP (MJ)
10
1
0.1
0.01
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
PHOTON ENERGY (KEV)

X-Ray Spectrum at 0.03 nsec

The accompanying time integrated x-ray spectrum is taken at only 0.03 nsec into the burn. It very clearly shows how x-rays beyond the K-edge of the tamper material are escaping while those below this energy are absorbed. The tamper material has not yet absorbed enough energy to raise its temperature much above the 150 eV that it was initialized to at the start of the calculation.



INTEGRATED RADIATION SPECTRUM

Ion Spectra

The ion spectra cannot be accurately computed because the Lagrangian hydrodynamics code only gives fluid velocities. Therefore we allow the target to expand until it no longer radiates an appreciable amount of energy. The energy remaining in the expanding plasma is called the ion energy. This energy is divided by the total number of atomic mass units in the plasma. This normalized energy of 0.85 keV/amu is then multiplied by the weight of each ion specie to estimate its average energy.

ION SPECTRA

ION YIELD	7.4 MJ
NORMALIZED ENERGY	0.85 keV/amu
D	1.70 keV
T	2.55 keV
He	3.40 keV
Li	5.90 keV
Pb	176.0 keV