HXS Field Test Plan

John Seely, finalized 14 August 2000

Introduction

The Hard X-Ray Spectrometer (HXS) is scheduled to be delivered to LLE on Monday, 13 November 2000. The instrument's Static Test Plan will be carried out during that week. The OMEGA shots for the HXS field test are scheduled for the following Tuesday, 21 November 2000. Considering that the instrument's performance and the CCD images must be evaluated after each OMEGA shot, for planning purposes we assume that time will permit x-ray data to be collected on six OMEGA target shots. It is possible that more shots can be carried out during the one day of shots. In addition, it is possible that the instrument can be fielded during the previous week on a ride-along basis for the purpose of testing the instrument's electronics.

The Field Test Plan (FTP) is designed to verify the functionality of the HXS instrument on OMEGA target shots. The instrumental features and capabilities that are relevant to the FTP are the following:

1. X-ray spectral image is recorded by a CCD x-ray detector.
2. Energy coverage is 12 keV to 60 keV.
3. Resolving power 100-400 depending on the energy range and the detector spatial resolution.
4. Nosecone Be filter functions as a blast shield while passing the x-ray energies of interest.
5. Step-wedge filter provides a range of CCD exposure levels.

The targets for the FTP will be krypton-filled CH shells of the type shot on OMEGA by Barukh Yaakobi and colleagues.[1] The krypton K-shell spectra near 13 keV will provide a good test of the spectrometer's resolving power. Moreover, of scientific interest, these spectral lines can be used for the implementation of spectroscopic diagnostic techniques for the determination of the electron temperature and density. The diagnostic techniques are based on those successfully developed for the argon K-shell spectra.

It is desirable to keep the targets generically the same on the six shots and to vary, optimize, and quantify the HXS operating parameters. We considered including in the FTP krypton-filled Be hohlraums of the type studied by the group lead by Tina Back.[2] However, the hohlraum targets were considered to be too complicated to manufacture in light of the goals of the FTP. In addition, the alignment of these targets is time consuming and would reduce the number of shots during the one day of tests. Although the hohlraum targets will not be implemented for the FTP, Martin Laming of NRL (who participated in the work with Tina Back) has provided simulated spectra and detector count levels for the hohlraum targets.[3] The modeling of the expected spectra indicates that the spectra from the krypton-filled CH shells are brighter than the spectra from the krypton-filled hohlraums. Thus the krypton-filled CH shells were chosen for the FTP on the basis of target simplicity, ease of target alignment, and spectral brightness.

K-shell radiators were chosen over L-shell radiators for the FTP because experiments indicate that K-shell radiators are more efficient than L-shell radiators at high laser powers. At lower laser powers, (< 1 TW) the reverse is true. In addition to the K-shell emission, these targets are intense sources of high-energy bremsstrahlung emission, arising as plasma electrons are accelerated by plasma waves excited by the incident laser beam. The bremsstrahlung emission may be directly observed in the hard x-ray spectrum, and the hot electron population can also affect the K-shell Kr line ratios.

Krypton-Filled Hohlraum Spectra

Shown in Fig. 1 is the simulated krypton emission spectrum for a 20%Kr/80%Xe hohlraum and assuming an idealized spectral resolution of $E/\Delta E=3000$.[3] The counts/bin are photons emitted into 4π during the 2 ns laser pulse. The most intense krypton He-like and Li-like satellite transitions are identified. The experimental wavelengths and energies of the intense krypton He-like and H-like spectral lines are listed in Table 1. The approximate resolving powers ($E/\Delta E$) required to observe adjacent lines are listed in the last column.

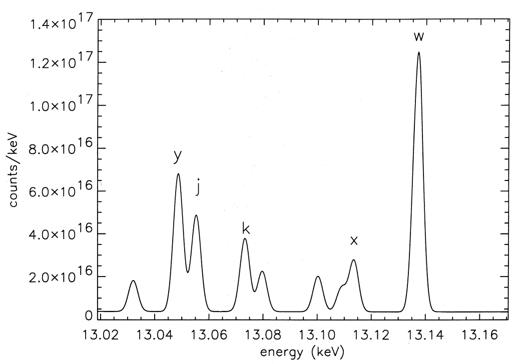


Fig. 1. Simulated krypton emission spectrum for a 20%Kr/80%Xe hohlraum and assuming a spectral resolution of $E/\Delta E=3000$. The most intense He-like (w,x,y) and Li-like satellites (j,k) are identified.

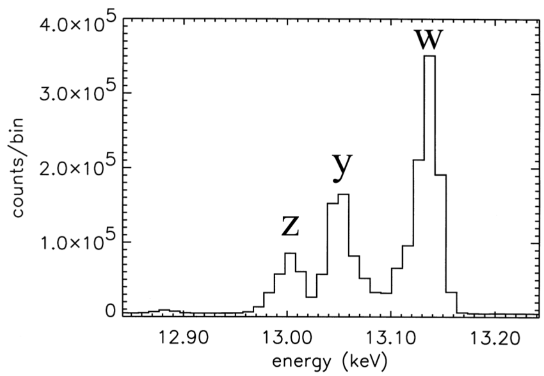


Fig. 2. Simulated krypton spectrum for a 100%Kr hohlraum and assuming a spectral resolution of $E/\Delta E=600$. The three strong features are (from the left) the forbidden line (z), intercombination line (y), and resonance line (w) of He-like Kr.

Table 1. The Most Intense Krypton K-Shell Transitions

Identification	Transition	Wavelength (Å)	Energy (keV)	Interval (eV)	Resolving Power
Kr^{+35} ($L\alpha_1$)	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{3/2}$	0.91783	13.509	-	
Kr^{+35} ($L\alpha_2$)	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{1/2}$	0.92327	13.429	80	200
Kr^{+34} (DS)	$1s2p\ ^1P_1$ - $2p^2\ ^1D_2$	0.9360	13.25	180	100
Kr^{+34} (w)	$1s^2\ ^1S_0$ - $1s2p\ ^1P_1$	0.94540	13.115	135	150
Kr^{+34} (y)	$1s^2\ ^1S_0$ - $1s2p\ ^3P_1$	0.95181	13.026	89	200
Kr^{+34} (z)	$1s^2\ ^1S_0$ - $1s2s\ ^3S_1$	0.95520	12.980	46	300

The photon flux estimate for the HXS spectrometer was based on LASNEX simulations of the hohlraums studied on NOVA.[3] Recent experiments on OMEGA indicate that the x-ray flux is higher than on NOVA.[2]

The NOVA targets were of 1 mm radius and 1.6 mm length, filled with gas to 1 atm pressure. We now consider a hohlraum filled with 100% Kr. The LASNEX output was postprocessed with a time dependent ionization balance code for Kr ions, including the Be-like through bare charge states. For five NOVA beams incident from each direction, amounting to 30-40 kJ laser energy, Kr is readily ionized to the He-like charge state, and an insignificant population of H-like ions is predicted to be present. A synthetic time-integrated spectrum, based on the NOVA hohlraum simulation, but computed using a spectral resolution of $E/\Delta E = 600$, is shown in Fig. 2. We have taken a solid angle of 1.35×10^{-7} sr (coming from a 1 cm slit length at a distance of 50 cm from the target multiplied by a crystal integrated reflectivity of 6.76×10^{-6} sr), and a detector quantum efficiency of 0.08. The three strong features are (from the left) the forbidden line (z), intercombination line (y), and resonance line (w) of He-like Kr. The first two features are heavily blended with dielectronic satellites. The simulated signal to noise is rather high.

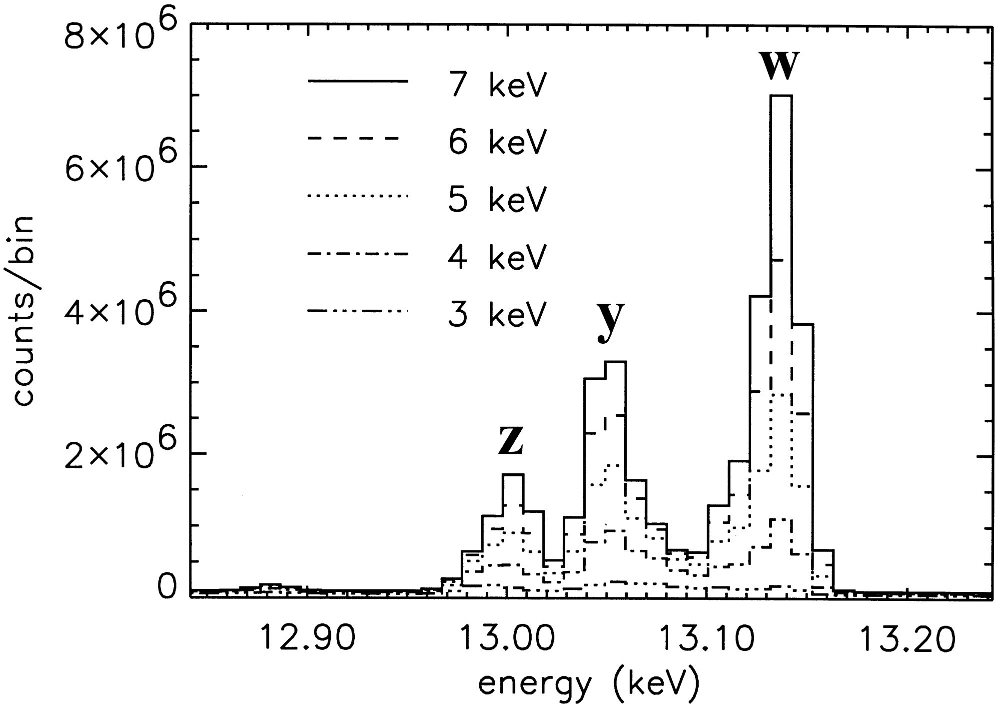


Fig. 3. Simulated krypton spectra for various electron temperatures.

To illustrate the change in the line ratios with temperature, we plot in Fig. 3 the same simulation, but this time for uniform assumed temperatures in the hohlraum of 3, 4, 5, 6, and 7 keV. The increase in line intensities with temperature can clearly be seen. In addition, the intensity ratio between the resonance line and the blend of the intercombination line changes, with the resonance line becoming progressively more dominant in the line complex as the temperature increases. These synthetic spectra use the same instrument characteristics as described above, with root-n Poisson noise added.

For these NOVA hohlraum targets, LASNEX simulations predict a very low population for the H-like Kr^{+35} ion.[2] However, our observation of hohlraums shot on NOVA do show some emission in Kr^{+35} (see Fig. 4).

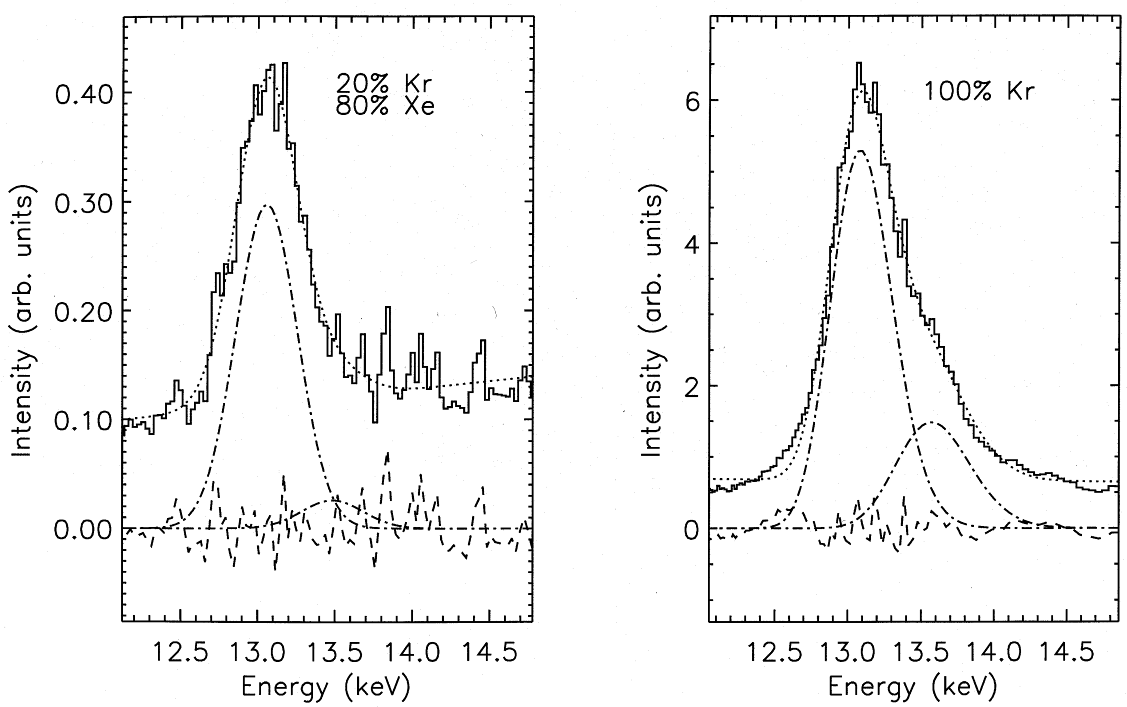


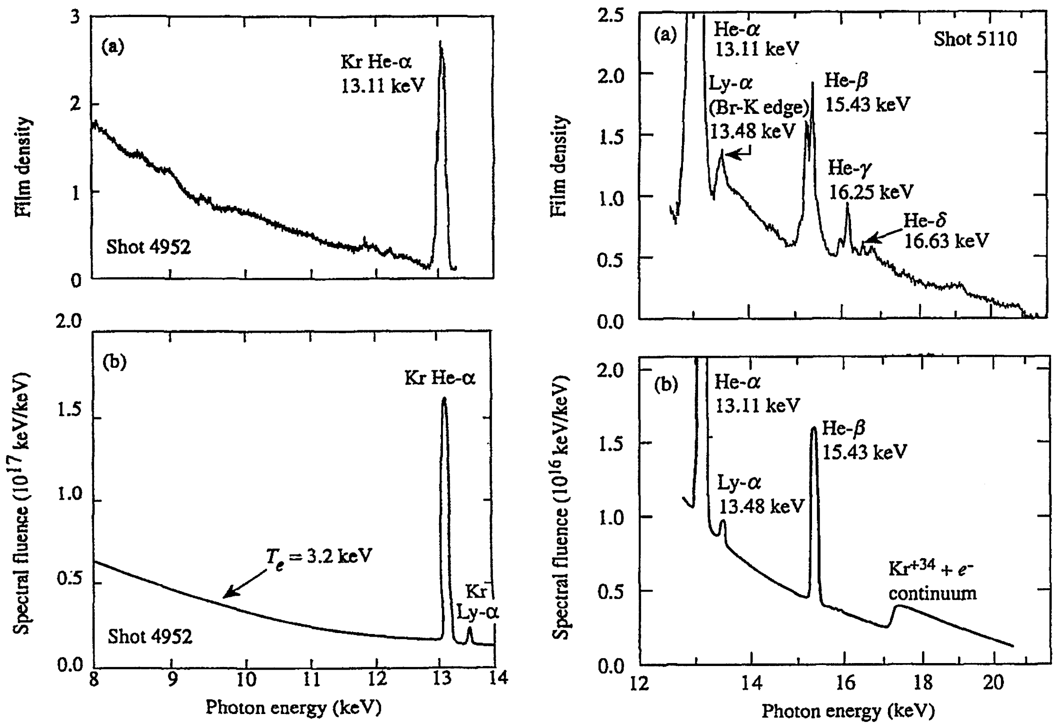
Fig. 4. The experimental spectra from 20%/80% and 100% Kr hohlraums. The dot-dashed curves are fits of the He-like resonance line (w) and H-like resonance line (Lyman-α) to the experimental spectra.

Krypton-Filled CH Shell Spectra

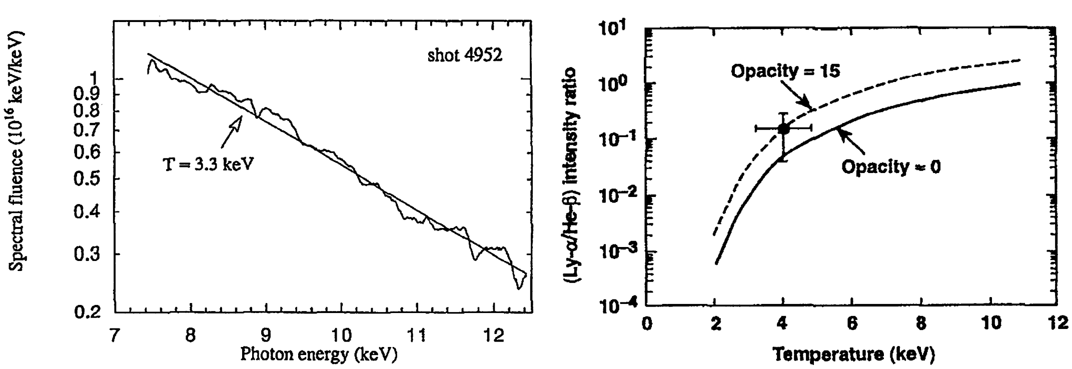
The data from the krypton-filled CH shells that were irradiated at OMEGA by Yaakobi *et al.*[1] are shown on the following page. The gas fill was 0.03 atm of Kr and 10 atm of D_2. For shot 4952, the spectrum recorded by a Si (111) crystal is shown. The linewidths indicate a resolving power of approximately 100. The spectrum covers the He-like Kr^{+34} resonance line w (identified as He-α in the spectrum) and the lower-energy continuum. The LILAC simulation is in good agreement with the experimental spectrum and indicates a peak spectral fluence in the He-α line w of $1.5x10^{17}$ keV/keV (radiation energy per unit of photon energy). The electron temperatures derived from the slopes of the experimental and calculated continua are 3.3 keV and 3.2 keV, respectively.

The spectrum recorded by a LiF (200) crystal on Shot 5110 is shown. This spectrum has a higher DEF film density owing to the mosaic nature and large integrated reflectance of the LiF crystal. The LILAC simulation indicates a peak spectral fluence of $1.5x10^{16}$ keV/keV and $1.0x10^{16}$ keV/keV in the He-β and Ly-α lines, respectively. The resolving power was approximately 100, lower than the 200 resolving power necessary to resolve the Lyman-α doublet. The electron temperature derived from the ratio of the He-β and Ly-α lines was 4 keV and was in reasonable agreement with the temperature derived from the slope of the continuum (3.6 keV).

Shot no.	Target diameter (μm)	Target thickness (μm)	DD pressure (atm)	Krypton pressure (atm)	Laser energy (kJ)
4952	870	10	10	0.03	23.6
5110	874	12.4	10	0.03	29.5



Krypton spectra from OMEGA Shot 4952 (left) and Shot 5110 (right).



Continuum spectrum from OMEGA Shot 4952 (left), and the electron temperature from Shot 5110 (right).

CCD Images

Shown in Fig. 5 is a typical spectral image recorded by a transmission crystal spectrometer developed by NIST. The image was recorded on a dental x-ray CCD detector. The spectrometer produces two spectral representations that are mirror images of one another. The instrumental zero wavelength position lies at the bisector of any pair of corresponding spectral features. This permits the energy axis to be self-calibrating. The CCD spectral image was integrated in the vertical direction to produce the lineout shown at the bottom of Fig. 5. The spectral images recorded by HXS on the OMEGA shots will be analyzed to determine the spectral resolution.

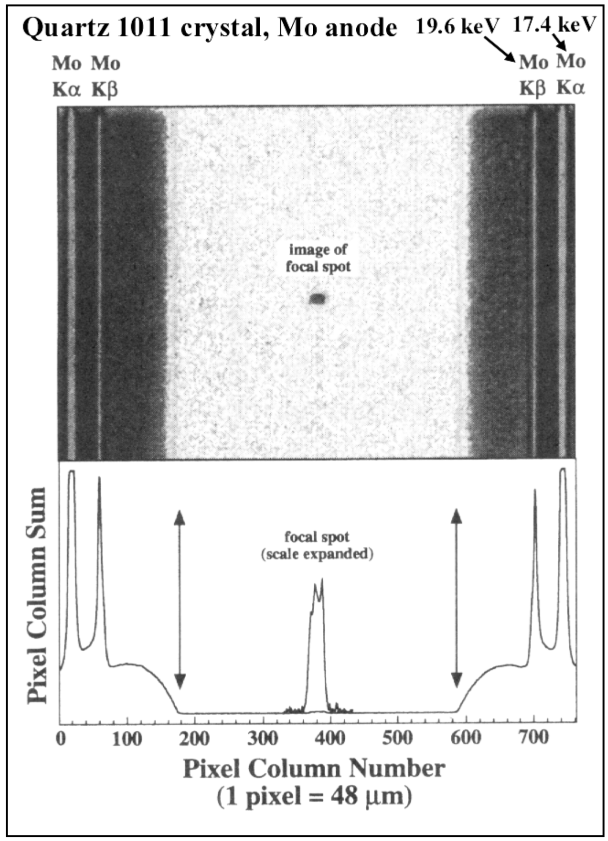


Fig. 5. A typical x-ray spectrum produced by a transmission crystal spectrometer and recorded on a CCD detector.

Filters

The thick beryllium filter in the nosecone serves as a blast shield while passing the x-ray energies of interest. As shown in Fig. 6 (top), the beryllium filters can be of thickness several mm and transmit approximately 80% of the 13 keV radiation.

The aluminum step-wedge filter on the spectrometer's aperture is intended to provide a range of exposure levels on the CCD detector. As shown in Fig. 6 (bottom), the aluminum filters of thicknesses 1 mil to 8 mil transmit 50% to 90 % of the 13 keV radiation.

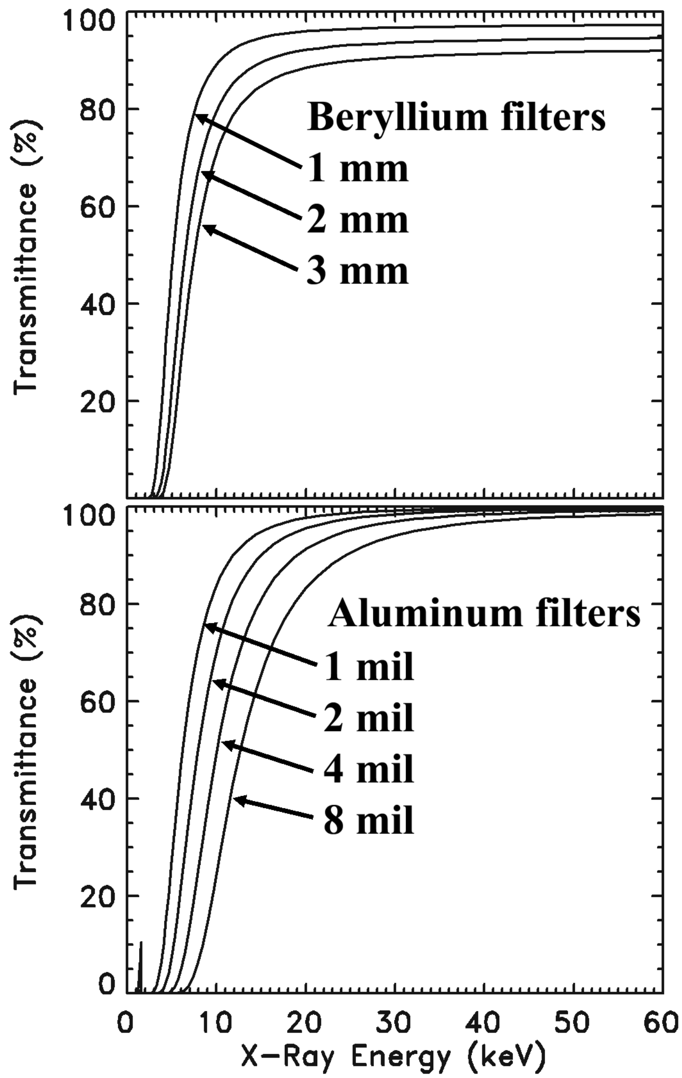


Fig. 6. The transmittances of the beryllium nosecone filter and the aluminum aperture filter.

Target Specifications

On the one day allotted to implement the HXS Field Test Plan, it is estimated that time will permit data will be collected on six OMEGA shots. This will allow time between shots for the analysis of the instrument performance and the analysis of the CCD images. The instrument's operating parameters will be optimized between shots. It is desirable to have a larger number of krypton-filled CH shell targets on hand in case the shots go quicker than expected. In addition, it is desirable to have CH shell targets with two different krypton fill pressures. The targets, provided by LLE, that are required for the FTP are the following:

Twelve (12) krypton-filled CH shell targets are provided by LLE. The CH shells have diameters in the range 800 μm to 900 μm. The shell thickness is in the range 10 μm to 12 μm. The CH shells are filled with 10 atm pressure of DD. In addition, six (6) of the CH shells have 0.03 atm krypton partial pressure, and six (6) of the CH shells have 0.06 atm krypton partial pressure.

References

1. B. Yaakobi, F. Marshall, and R. Epstein, "High Temperature of Laser-Compressed Shells Measured with Kr^{34+} and Kr^{35+} X-Ray Lines," Phys. Rev. E **54**, 5848 (1996).
2. C. A. Back, "X-Ray Sources Generated from Gas-Filled Laser-Heated Targets," 12th APS Topical Conference on Atomic Processes in Plasmas, March 19-23, 2000.
3. J. M. Laming, C. A. Back, C. Decker, J. Grun, U. Feldman, and J. Seely, "Modeling and Interpretation of Spectra from Kr/Xe Hohlraums," (preprint).