PHYSICAL REVIEW
LETTERS

VOLUME 2 APRIL 1, 1959 NUMBER 7

SOFT X-RAYS FROM A MAGNETICALLY COMPRESSED PLASMA IN SCYLLA*

K. Boyer, E. M. Little, W. E. Quinn,
G. A. Sawyer, and T. F. Stratton
Los Alamos Scientific Laboratory,
University of California,
Los Alamos, New Mexico
(Received March 12, 1959)

The Scylla plasma experiment[1] employs a rapidly rising magnetic field in cylindrical mirror geometry to heat a deuterium plasma. A proposed mechanism consists of Joule and shock heating in the early stages of the discharge followed by an adiabatic compression to produce a hot plasma centered in the discharge tube. Emission of neutrons from the plasma has been observed and earlier measurements[2] of the neutron energy spectrum suggest that a plasma ion temperature of about 1 kev is achieved at the time of peak magnetic compression in a region about 1.5 cm in diameter and 3 cm long. In such a plasma bremsstrahlung radiation should be emitted as the fast-moving electrons are deflected in the Coulomb fields of the ions. Soft x-ray emission is observed from the central plasma region of the discharge.

The x-rays were detected with a plastic scintillator and photomultiplier. A system of collimating slits inserted along the axis of the discharge tube allowed only radiation from the central 2 cm of the discharge volume to fall on the scintillator. Thin metal foils shielded the scintillation counter from visible light. Soft x-rays were emitted mainly on the second half cycle of current although some x-rays were observed on subsequent half-cycles. Neither soft x-rays nor neutrons were emitted on the first half-cycle. Figure 1 shows the time history of x-ray and neutron emission together with the magnetic field in the discharge tube. Careful time correlation of the soft x-ray yield with neutron emission showed that the start of emission of neutrons and the start of x-ray emission coincided exactly. Both x-ray emission and neutron emission had a bell-shaped time distribution with full-width at half maximum of 0.8 μsec, centered exactly with

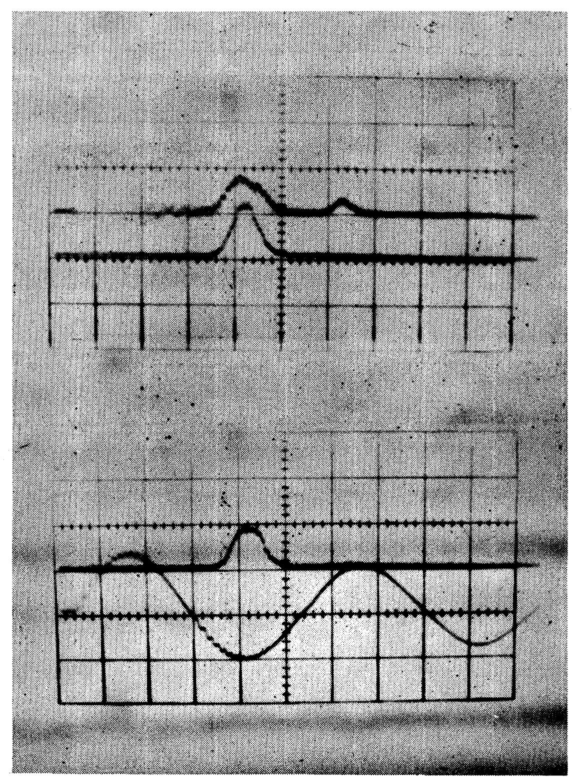

FIG. 1. Oscilloscope records of x-rays (top trace), neutrons (second and third traces), and magnetic field (bottom trace), showing that both neutrons and x-rays are emitted at the time of peak magnetic field in the second half-cycle. The time scale is 2 μsec per division.

the peak compression of the current cycle.

It was possible to obtain a photograph of the x-ray-emitting region with a pin-hole camera looking along the discharge axis. A pin-hole 1 mm in diameter accurately positioned on the coil axis and x-ray film protected from visible light by 1.46 mg/cm^2 aluminum foil produced the self-photograph shown in Fig. 2. The diameter of the x-ray-emitting region as determined from the photograph was 1.5 cm. It should be remarked that the diameter of the x-ray source established by the self-photograph agreed with the diameter of the neutron source as determined by an earlier collimated neutron experiment.

The energy of the x-rays emitted at the time of neutron emission was estimated by absorption measurements in thin foils of Be, Al, and Ni. The absorption coefficients deduced from the slopes of the transmission curves near the maximum transmission region indicated 0.9 kev from Be, 1.1 kev from Al, and 1.4 kev from Ni. In addition, the plot for Be, for which there were the best data over the widest range of absorber thickness, yielded 1.4 kev for the x-ray energy if the slope was drawn near the region of minimum transmission. From the curvature of the Be absorption plot it was clear that there was a distribution of x-ray energies which peaked in the neighborhood of 1 kev.

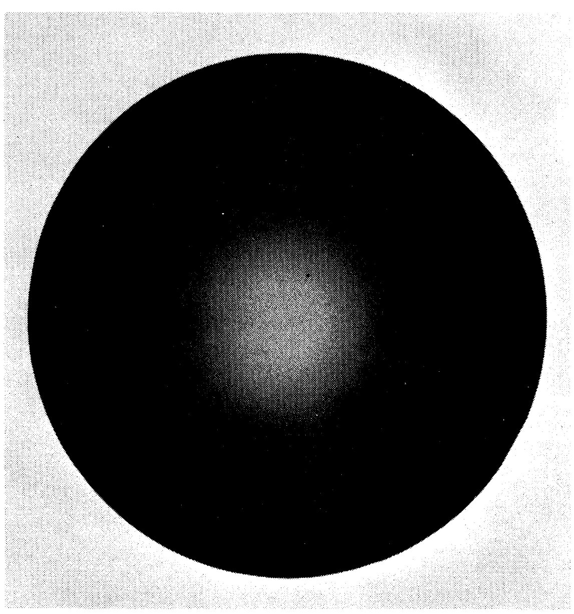

FIG. 2. Pin-hole photograph of the x-rays emitted from the compressed plasma in Scylla taken along the axis of the discharge tube. The circular boundary of the dark region corresponds to the tube wall.

The absolute intensity of the x-rays was determined from the integrated x-ray pulse height in a NaI(Tl) scintillation counter used in good geometry with an accurately positioned defining slit. The counter was calibrated with 300-kev and 1-Mev γ-ray sources. The pulse height vs energy characteristic of NaI(Tl) is known to be nonlinear at low quantum energy[3] but good data are not available at 1 kev quantum energy; the characteristic was assumed to be linear for these measurements. The x-ray yield measured in this way during the second compression cycle was 1.6×10^6 ergs. Correction for neutrons detected in the counter was less than 1%.

Calculation of the total free-free bremsstrahlung radiation from a plasma depends upon the temperature, density, and volume according to the relation[4]

$$Y=0.54\times10^{-30}n_i n_e Z^2 g T^{1/2} V,$$

where T is in kev and Y is in watts. The best estimates for the particle density and reaction volume at peak compression are $n_i=n_e=10^{17}\text{ cm}^{-3}$, $V=6\text{ cm}^{-3}$. For a plasma of this density and volume with a temperature of 1 kev, the calculated total radiation is 3×10^5 ergs for a pulse corresponding to the observed x-ray pulse shape and length. The calculated bremsstrahlung yield is a factor 5 lower than the observed x-ray yield, but this is considered fair agreement considering the assumptions involved in the calculation.

The region of x-ray emission and the time history support the concept of a centrally located hot plasma created by magnetic compression. The x-ray yields and spectral distribution are consistent with bremsstrahlung from a plasma at an electron temperature of 1 kev.

We wish to acknowledge the helpful advice and support of James L. Tuck.

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]Elmore, Little, and Quinn, Phys. Rev. Lett. 1, 32, (1958).

[2]Boyer, Elmore, Little, and Quinn, Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958 (United Nations, Geneva, to be published); Boyer, Elmore, Little, and Quinn, The Edited Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958 (Pergamon Press, London and New York, to be published).

[3]D. Engelkemeier, Rev. Sci. Instr. 27, 589 (1956).

[4]R. F. Post, Revs. Modern Phys. 28, 338 (1956).

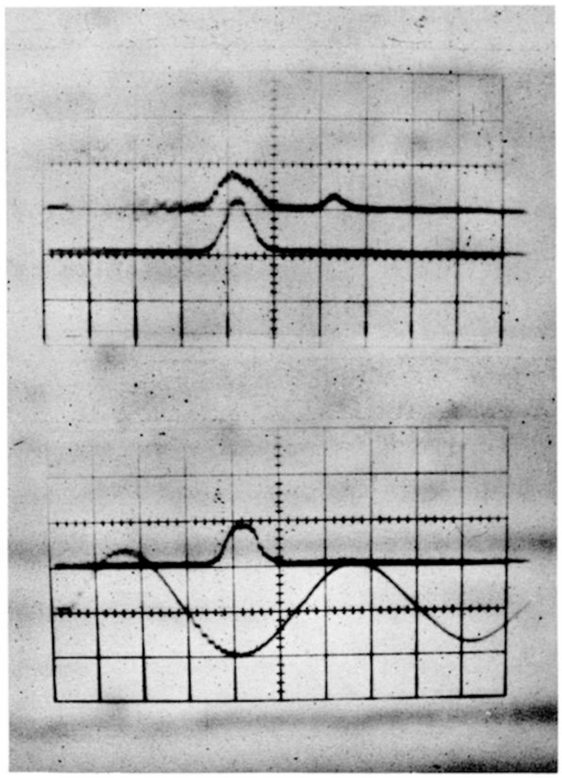

FIG. 1. Oscilloscope records of x-rays (top trace), neutrons (second and third traces), and magnetic field (bottom trace), showing that both neutrons and x-rays are emitted at the time of peak magnetic field in the second half-cycle. The time scale is 2 μsec per division.

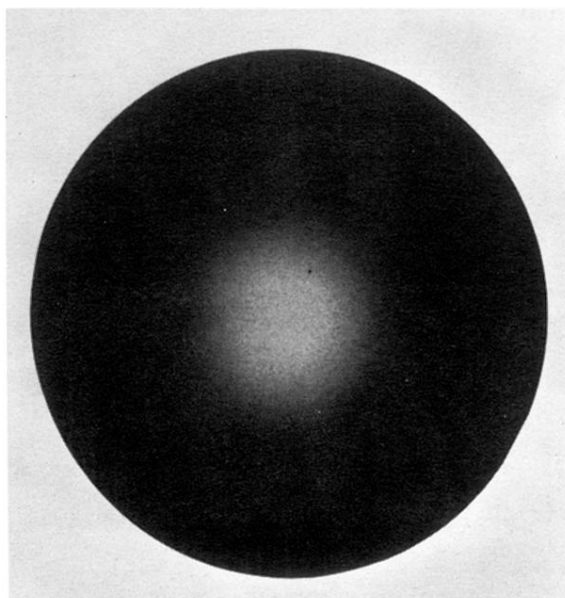

FIG. 2. Pin-hole photograph of the x-rays emitted from the compressed plasma in Scylla taken along the axis of the discharge tube. The circular boundary of the dark region corresponds to the tube wall.