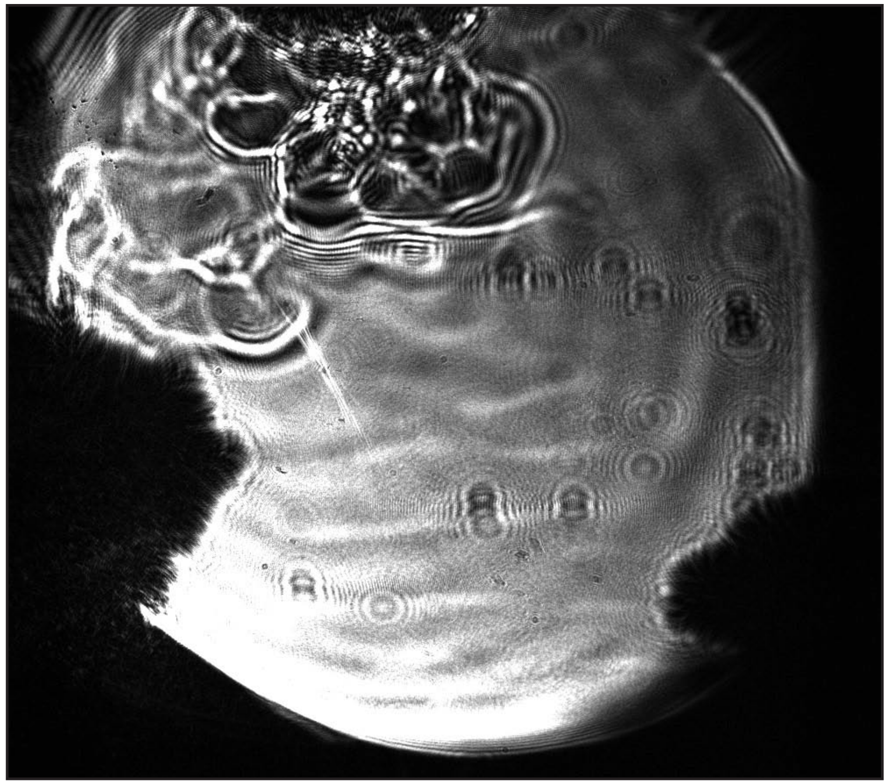
First Tests on OMEGA of a Bubble Chamber for Neutron Detection



M. C. Ghilea
University of Rochester
Laboratory for Laser Energetics

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Summary

The 14-MeV-neutron sensitivity of a freon-based bubble detector has been tested on OMEGA

- The chamber has detected 14-MeV DT neutrons at yields of $\sim 10^{13}$.
- The measured sensitivity agrees with that calculated for neutron–freon bubble formation/growth.
- The sensitivity is too low for neutron imaging on OMEGA, but more than adequate for the higher neutron yields expected at the NIF.

Collaborators

T. C. Sangster

D. D. Meyerhofer

D. J. Lonobile

University of Rochester
Laboratory for Laser Energetics

Neutron imaging can provide data that show why an ICF capsule fails to ignite[1,2]

- Neutron images of ICF capsules provide a direct measurement of the fusion burn region within a compressed target.
- The radiation symmetry can be inferred from a neutron image of the hot-spot fusion region (where the fusion processes occur).
- Bubble chambers are detectors with a high potential in achieving high resolution neutron images[3].

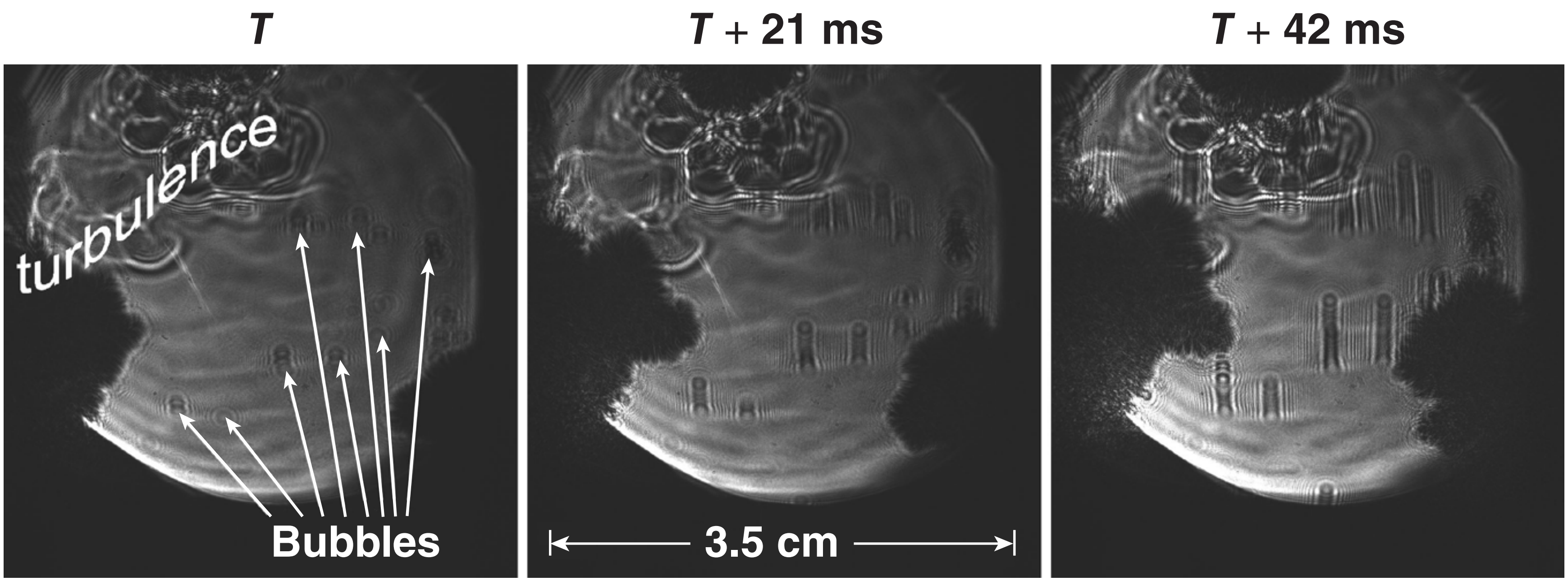
[1] L. Disdier *et al*., Nucl. Instrum. Methods Phys. Res. A 489, 496 (2002).
[2] R. A. Lerche *et al*., Rev. Sci. Instrum. 74, 1709 (2003).
[3] R. K. Fisher *et al*., Phys. Plasmas 9, 2182 (2002).

The bubble chamber is a fully self-contained platform located in the OMEGA Target Bay

- Neutron interactions in the superheated freon create bubbles that are counted/imaged.
- The bubbles are detected in parallel, monochromatic light.
- For imaging, distribution of bubbles ~ neutron spatial distribution.

E17366

The number of observed bubbles inside freon confirmed the theoretical calculations



- Successive images (21-ms difference) of neutron-induced cavitation inside the BUBDET: about 14 bubbles can be counted in the area not affected by turbulence.

E17367

Nucleation occurs inside a bubble chamber when the deposited energy reaches a threshold value

- Thermodynamics of the superheated liquid gives the threshold energy to create a bubble:*

$$W_{\text{bubble}} = \frac{16\pi\gamma^3}{3(p_v - p_0)^2},$$

γ: surface tension of the active medium
p_v: co-existence phase pressure
p_0: superheated state pressure

- Maximizing the free energy necessary to form a bubble, the critical radius from which a bubble does not collapse but continues to grow is

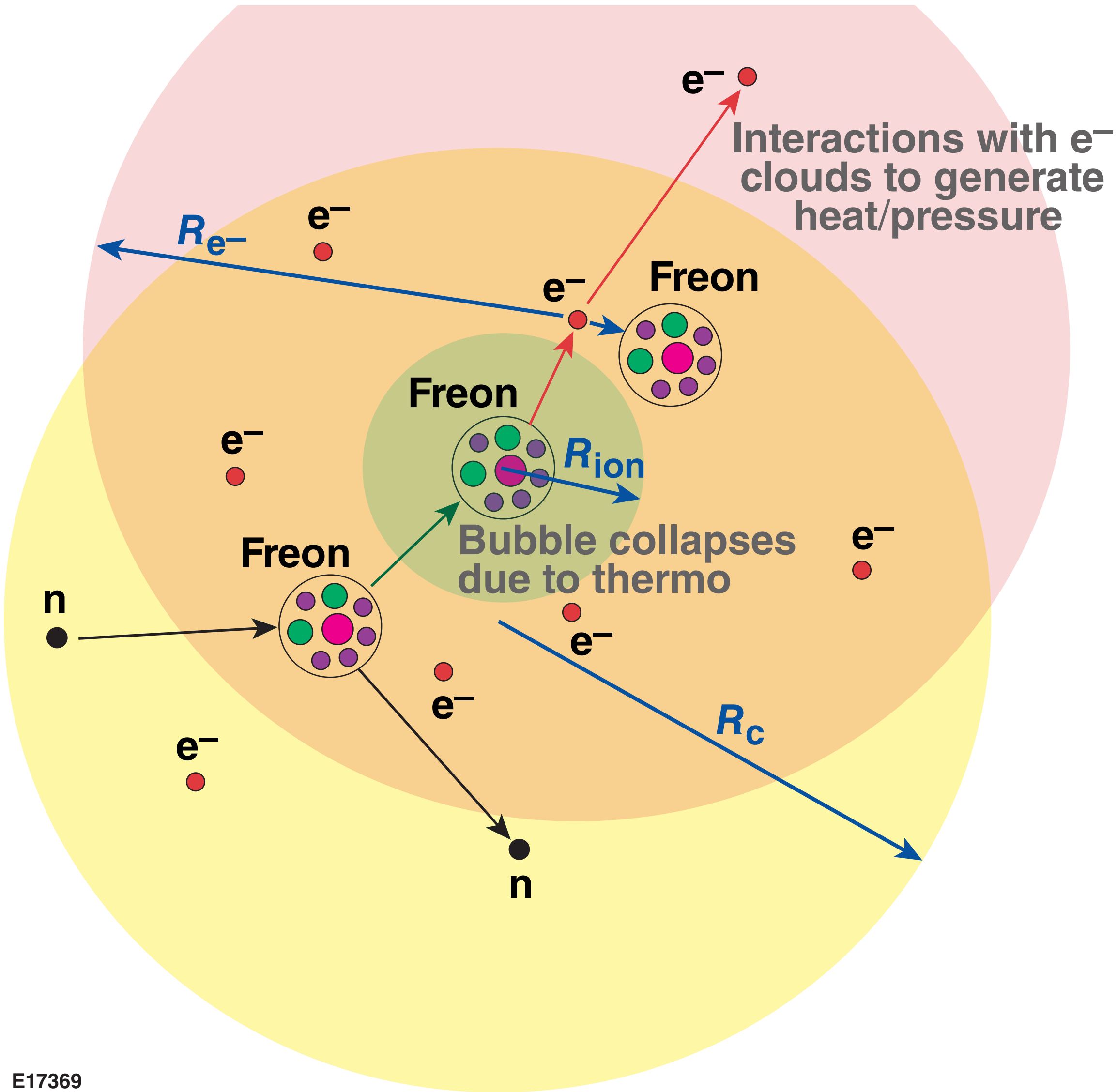
$$R_c = \frac{2\gamma}{p_v - p_0}.$$

- Therefore, for a thermodynamically viable bubble, the energy W_{bubble} must be deposited over a volume $\sim R_c^3$.
- However, the ion-recoil range for $(n,\text{freon}) \rightarrow (n',\text{freon}')$ is $\ll R_c$.

E17368

*M. Das *et al.*, Radiat. Meas. 30, 35 (1999).

The sensitivity of bubble formation can be understood by examining the details of ion recoil



- Since the recoil-ion range is short, energy must be deposited in a volume ~R_c^3 by energetic (several hundred eV) electrons.
- Furthermore, only a small fraction of the recoil ions have energies >W_{bubble} (~2 keV for freon 115).

E17369

The number of bubbles generated per source neutron can be expressed by a simple equation

- For a given solid angle of the bubble detector $d\Omega$, the number of bubbles per neutron source can be expressed as

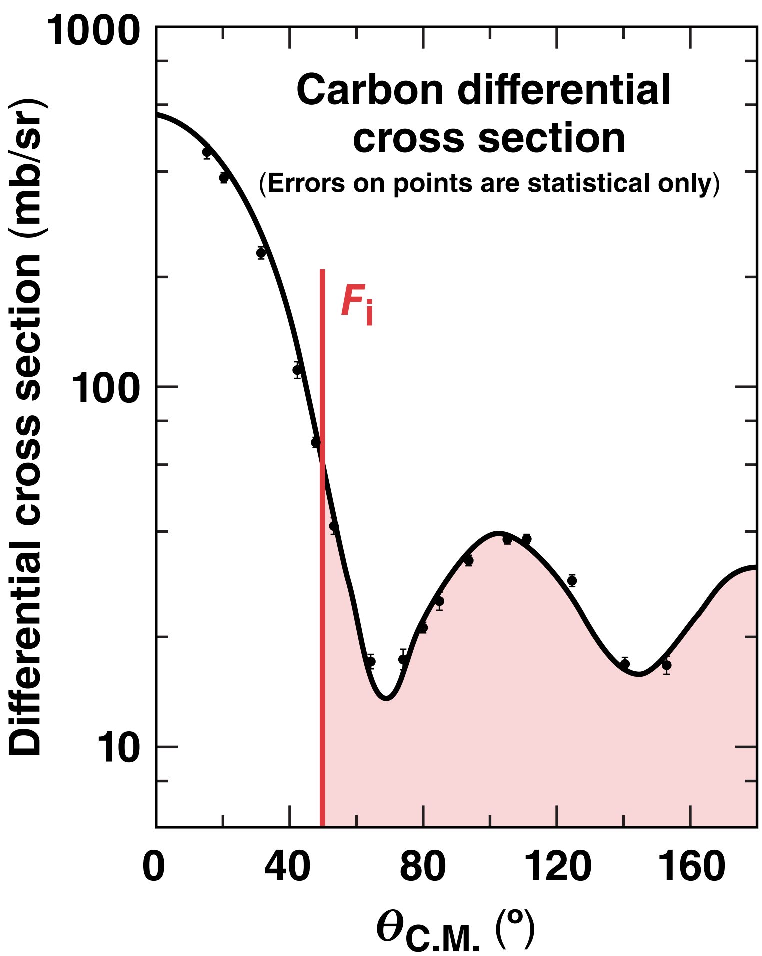
$$\frac{\text{number of bubbles}}{n_{\text{source}}} = F_n \cdot F_i \cdot F_e \cdot d\Omega.$$

F_n is the fraction of the incident neutrons interacting with the superheated liquid.

F_i is the fraction of the ejected ions with energy $\geq W_{\text{bubble}}$.

F_e is the fraction of the ejected ions that induce, on scattered electrons, an energy $\geq W_{\text{bubble}}$ and range ~R_C, and produce bubbles.

The interaction coefficients from the previous slide can be easily calculated



- F_n (the fraction of incident neutrons) can be calculated based on the total scattering cross section.
- F_i (the fraction of the ejected ions with energy $\geq W_{bubble}$) can be calculated based on the differential cross section (>50° for the case of freon).
- F_e (the fraction of the ejected ions that produce bubbles) can be calculated from the interaction cross section between a recoil nucleus and an electron**

$$\sigma_{i,e} = 18.74 \times 10^{-21} \frac{Z_e R_h}{W_{bubble}} \left(cm^2\right),$$

where Z_e is the number of electrons/ molecule and R_h is the Rydberg energy.

*A. J. Frasca *et al*., Phys. Rev. 144, 854 (1966).
**F. Seitz, Phys. Fluids 1, 2 (1958).

The number of bubbles/neutron sources can be estimated for the LLE freon bubble detector

UR LLE

- For the case of freon 115 (CCl_2Fl_5) at 50ºC
  - $F_n = 0.243$
  - $F_i = 0.08$
  - $F_e = 5.719 \times 10^{-5}$
- Therefore, for the detector's solid angle

$$\text{Neutron sensitivity} = \frac{\text{number of bubbles}}{n_{\text{source}}} = F_n \cdot F_i \cdot F_e \cdot d\Omega = 1.33 \times 10^{-12}$$

- For the set of images shown earlier (subtracting the turbulence area from $d\Omega$), the neutron yield is $y_n = 10^{13}$.
- After subtracting the turbulence area, expected number of bubbles $\approxeq$12.

E17372

Neutron yield at the NIF will be sufficient to obtain a high-resolution neutron image

Penumbral/pinhole imaging with bubble chambers requires at least 10^3 to 10^4 bubbles inside the detector for a 4-μm to 1-μm resolution of the neutron source image (for a magnification $M = 30$).

OMEGA	NIF
Source-detector distance – 8 m	Source-detector distance – 16 m
FOV – 200 μm	FOV – 200 μm
Neutron yield ~10^{13}	Neutron yield ~10^{19}
No. of bubbles observed ~14	No. of bubbles expected ~3×10^6

Neutron yield at the NIF will reach $y_n = 10^{19} \rightarrow 10^6$ bubbles can be produced, more than enough for a high-resolution neutron image.

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