Abstract

GENERAL ATOMICS

<u>Single-Gas Bubble Neutron Detectors For Alpha Knock-On Tail Measurements</u>* R.K. Fisher, A. Belian,† E. Morse,† and P.B. Parks, *General Atomics* — Measurement of the neutron energy spectrum above ~16 MeV will yield information on the spatial and energy distributions of confined fast alphas in DT tokamaks. The energetic neutrons result from fusion reactions involving the energetic ions created by alpha-fuel ion knock-on collisions. Standard two-gas bubble neutron detectors, designed to only detect neutrons with energies above a selectable threshold determined by the gas mixture, were used in preliminary attempts to measure the knock-on neutrons from DT plasmas in TFTR and JET. Subsequent measurements at accelerator neutron sources showed an unexpected below-threshold detector response that prevented observations of the alpha-induced neutron tails. Spontaneous bubble nucleation measurements show that this below-threshold response is due to slight variations in the gas mixture, and is not present in single-gas detectors. Single-gas detectors will be tested at Ohio University and at UC Berkeley to determine the neutron energy threshold as a function of detector operating temperature, and to confirm the lack of a below-threshold response. An array of single-gas detectors operating at different temperatures should allow measurements of the alpha knock-on neutron tail during the planned DTE2 experiments on JET, which are presently scheduled in 2002.

***Research supported by U.S. DOE Grant DE-FG03-92ER54150**

†UC Berkeley

GENERAL ATOMICS

NEED FOR ALPHA DIAGNOSTICS

GENERAL ATOMICS

- How well the alphas are confined and heat a DT plasma will determine how difficult it will be to reach fusion ignition.

- Alpha particle transport has been shown to be affected by large sawtooth instabilities, TAE modes, toroidal field ripple, and reversed shear operation in TFTR experiments.

- Other alpha diagnostics under development have limited capabilities and will be difficult to implement on large tokamaks including JET and ITER

ADVANTAGES OF KNOCK-0N TECHNIQUE

GENERAL ATOMICS

- Measurements of the knock-on DT neutron tail will provide information on the confined alpha population and energy distribution:

  * including information on the alphas in the hot plasma core where ignition should begin and where most other alpha diagnostics will have difficulty.

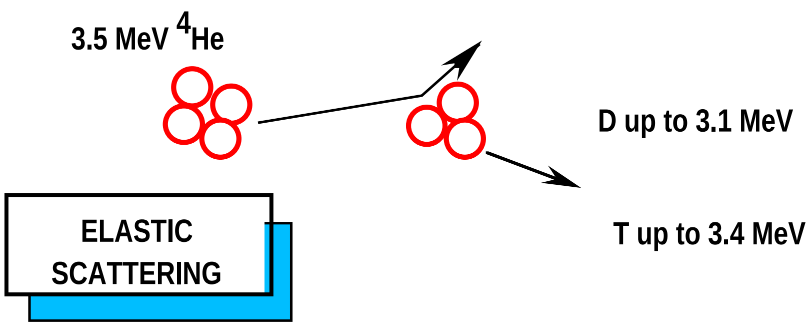
  * method is non-perturbing to the plasma, no vacuum pentrations or difficult port access are required.

  * neutron spectroscopy is readily applicable to ITER and other future fusion experiments; becoming even easier to implement as neutron output increases.

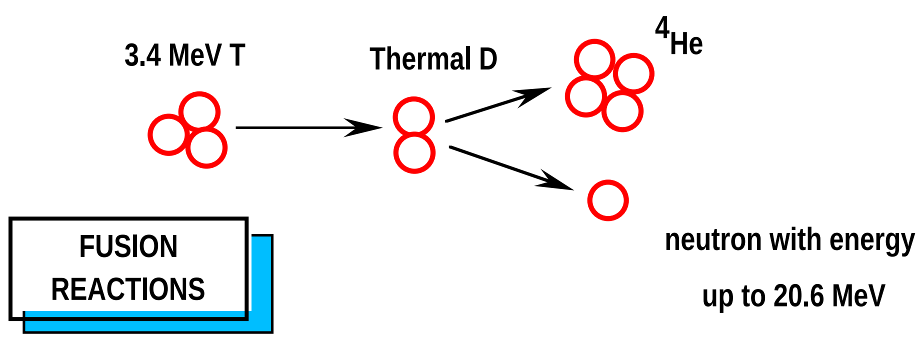
NEW TECHNIQUE TO MEASURE CONFINED ALPHA PARTICLES

GENERAL ATOMICS

Presence of alphas creates high energy D, T ion tails



Energetic ion tails produce tail on DT neutron distribution



R.K. Fisher, *et. al.*, "Fast Alpha Particle Diagnostics Using Knock-On Ion Tails", Nuclear Fusion 34, 1291 (1994).

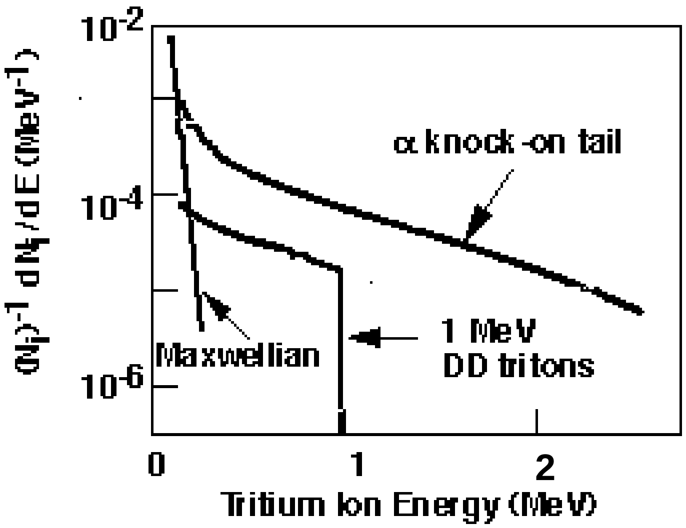
GENERAL ATOMICS

PREDICTED SIZE OF KNOCK-ON TAILS

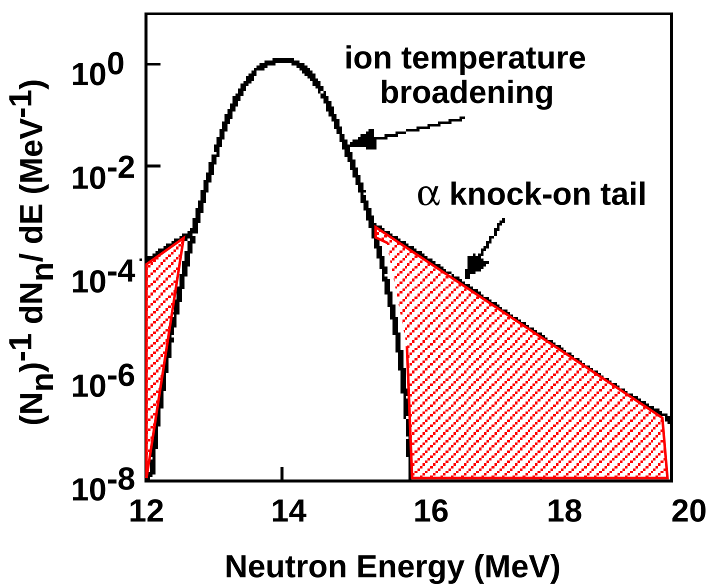
GENERAL ATOMICS

Calculated Tritium Ion Tail in ITER

(at $n_e = 2n_d = 2n_t = 8 \cdot 10^{13} cm^{-3}$ and $T_i = T_e = 17$ keV)



Calculated DT Neutron Tail in ITER



- **Small size of knock-on tail requires detector insensitive to much larger flux of DT neutrons below 16 MeV**

GENERAL ATOMICS

PHYSICS OF BD THRESHOLD

- **Neutron produces either zero or one bubble**

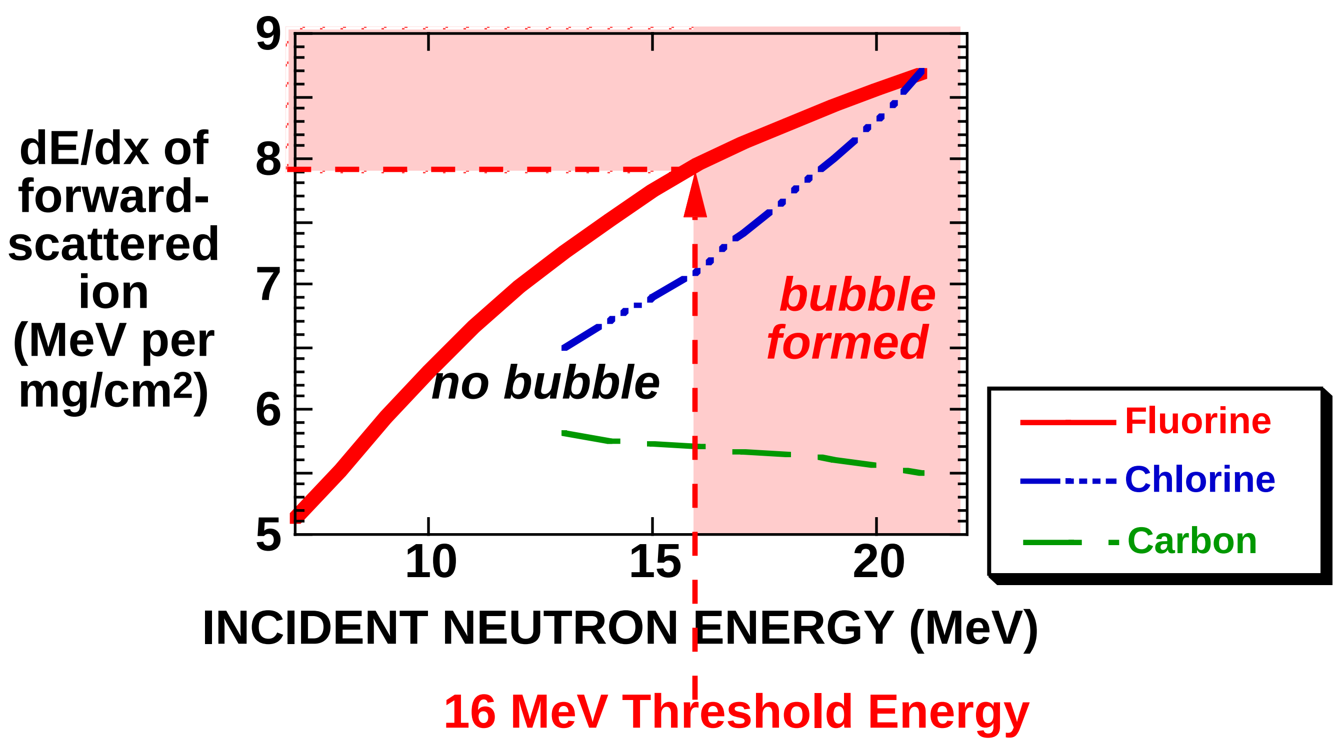
- bubble production requires dE/dx ~ E_c / $2r_c$

E_c =critical energy or minimum energy required to form a bubble

r_c = critical radius or minimum radius needed for bubble growth

- neutron collides with atom of mass A in BD, producing a recoil ion of energy:

$$E_A = E_n \{ 4A \cos^2(\theta_A) \}/(1 + A)^2$$



- **Hence only a recoil ion resulting from a nearly head-on collision {cos(θ_A) ~ 1} can deposit required energy since dE/dx is increasing with energy**

- **detectors with thresholds between 14 and 20 MeV can be designed by mixing two detector liquids**

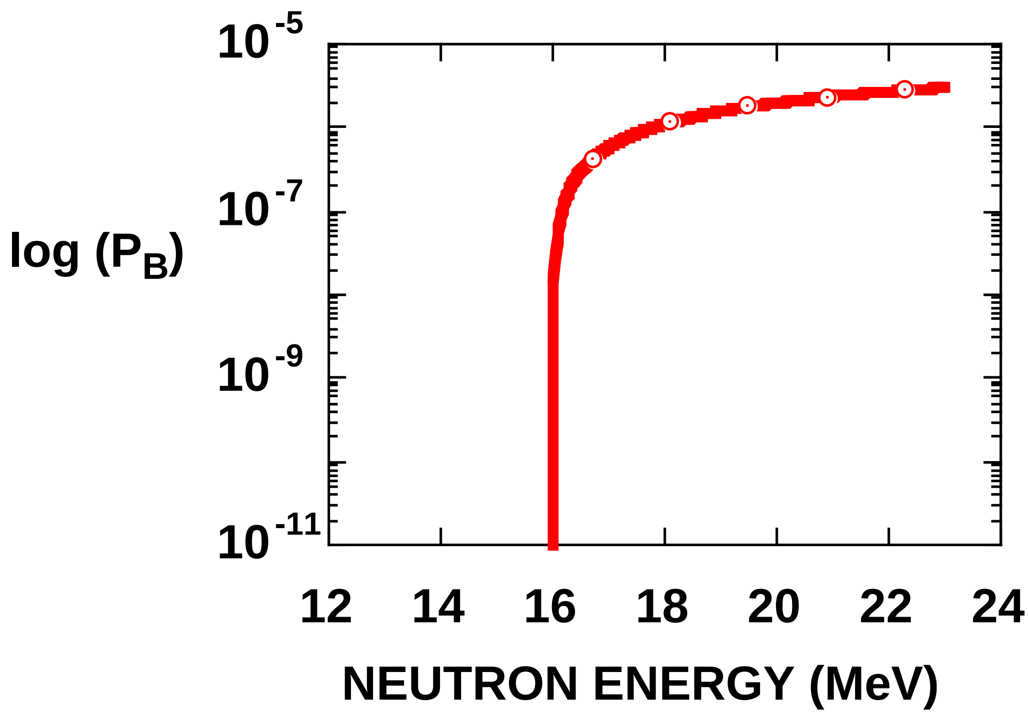
e.g. Freon-12 with E_c = 16 keV and Freon-114 with E_c = 707 KeV

PREDICTED BD RESPONSE

- **Probability of incident neutron scattering and producing a bubble is**

$$P_B = n_{fluorine}\, t_{BC} \int (d\sigma/d\Omega)\, d\Omega$$

$$\sim 10^{-5} (1 - E_{th} / E_n)$$

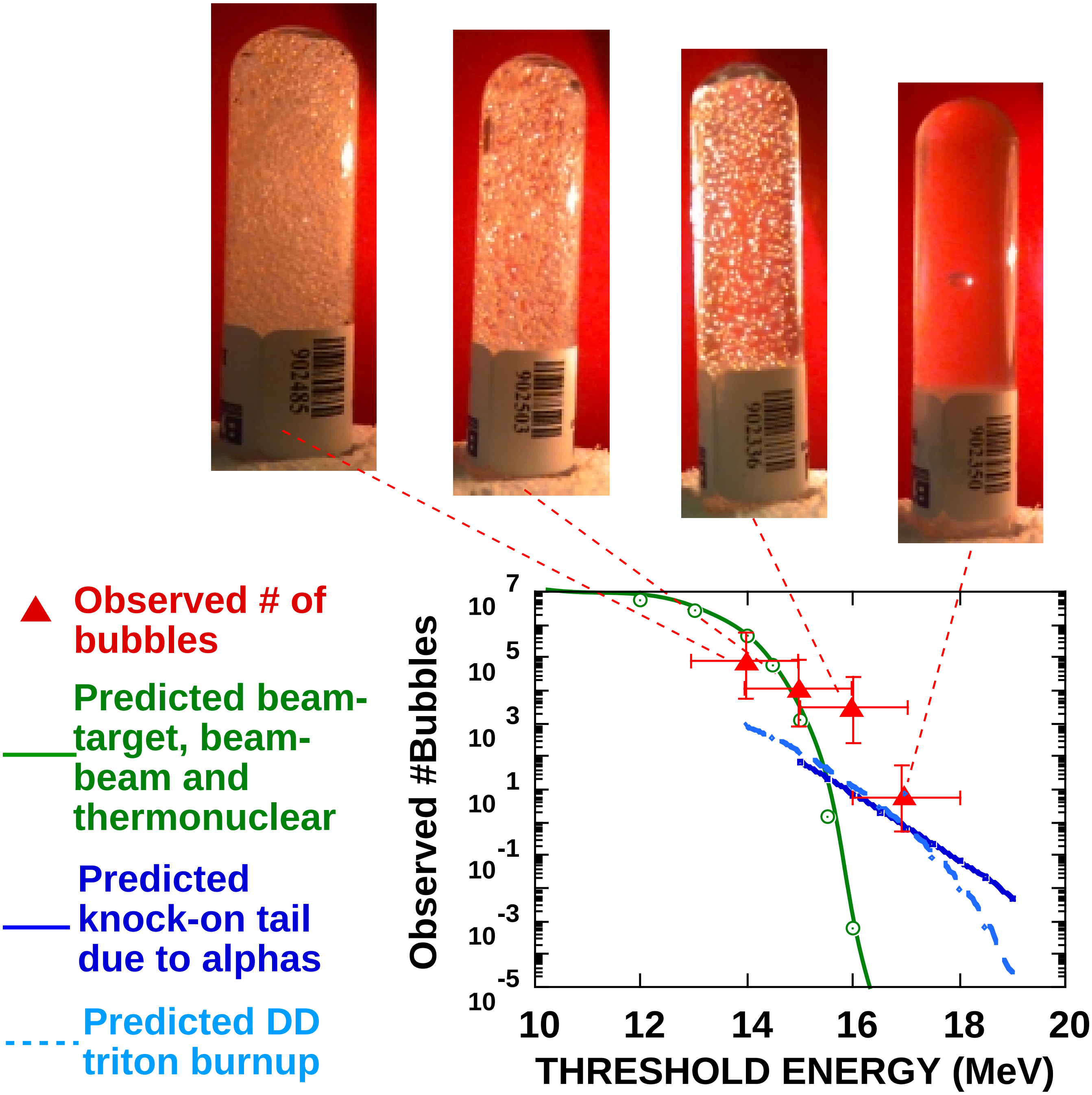


- **rapid rise in sensitivity above threshold reflects increase in fraction of neutron scattering interactions that result in a recoil ion of sufficient dE/dx**

- **no bubbles are produced by ions creating recoil electrons as in a conventional bubble chamber, nor is there a need to apply a magnetic field and measure an ion track**

- **measured gamma-ray sensitivity is very small (10^{-12} of neutron sensitivity)**

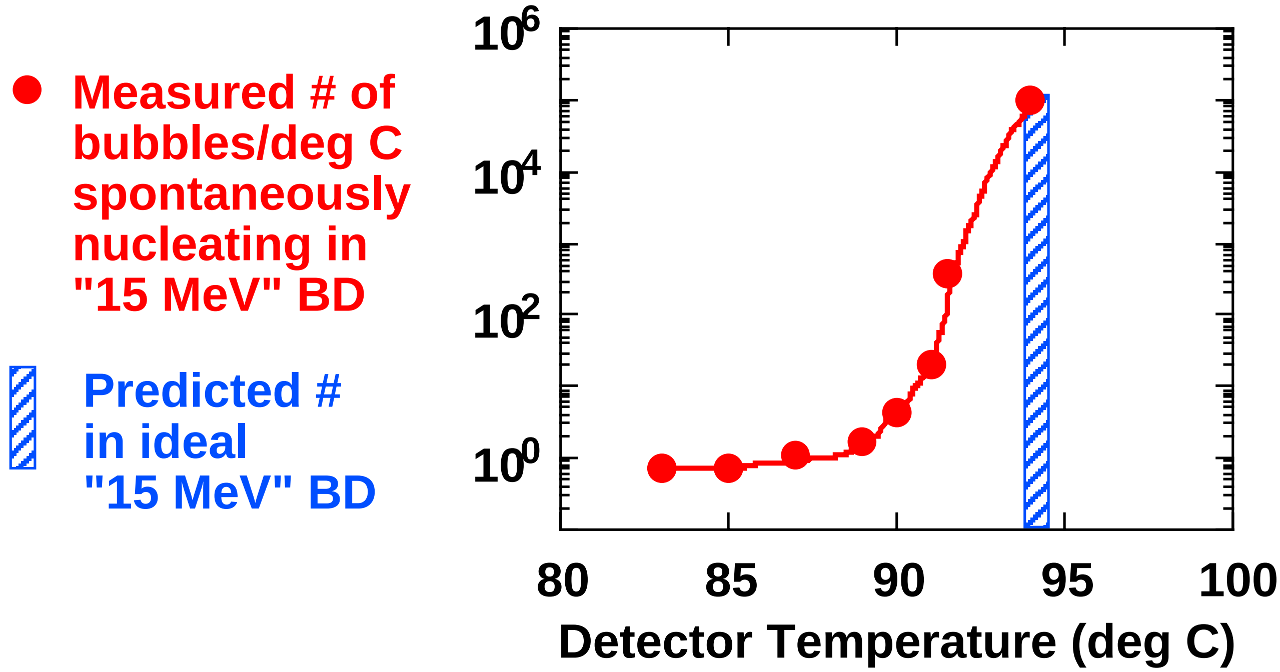
TFTR BD DATA SHOWED LARGER THAN EXPECTED NEUTRON TAIL SIGNALS



Measured BD signals above 16 MeV are much larger than beam-beam, beam-target or thermonuclear reactions

SPONTANEOUS NUCLEATION MEASUREMENTS USED TO DETERMINE BD RESPONSE "BELOW THRESHOLD"

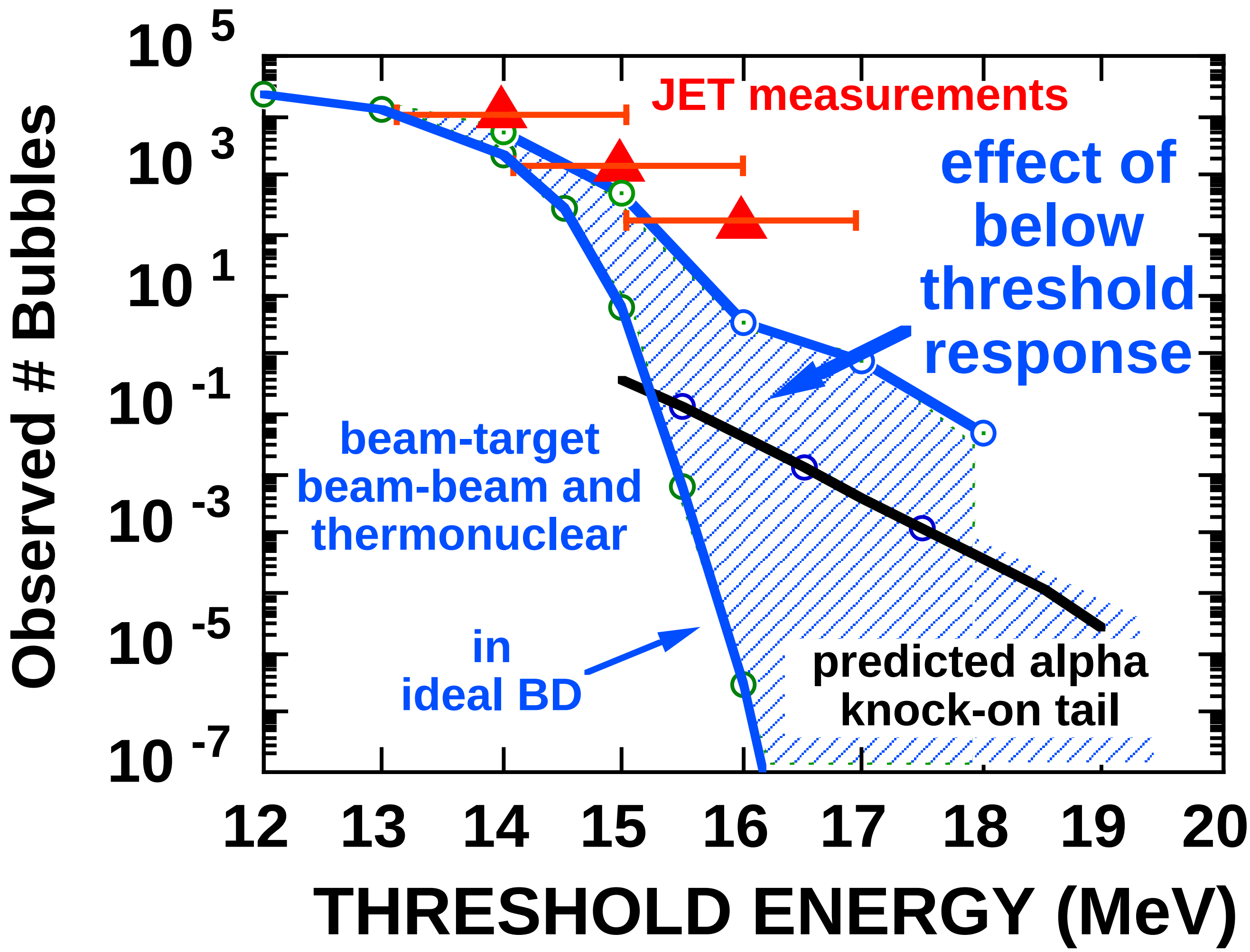
- **BD's consist of ~10,000 one hundred micron drops of superheated liquid suspended in a support gel**
- **RTNS results suggest some of the drops of bubble detector liquid may respond to lower energy neutrons**
- **Spontaneous nucleation of bubbles occurs at much higher temperatures, where the local thermal fluctuations in the liquid density can create clusters of vapor "holes"that reach the critical radius and spontaneously result in a bubble**



- **Results show that a small fraction of the drops of BD liquid in the detector have a lower spontaneous nucleation temperature and hence critical dE/dx and neutron energy threshold**

TOKAMAK RESULTS CONSISTENT WITH BELOW THRESHOLD RESPONSE

- **Below threshold response to beam-target, beam-beam, and thermonuclear neutrons explains larger than expected tokamak signals**



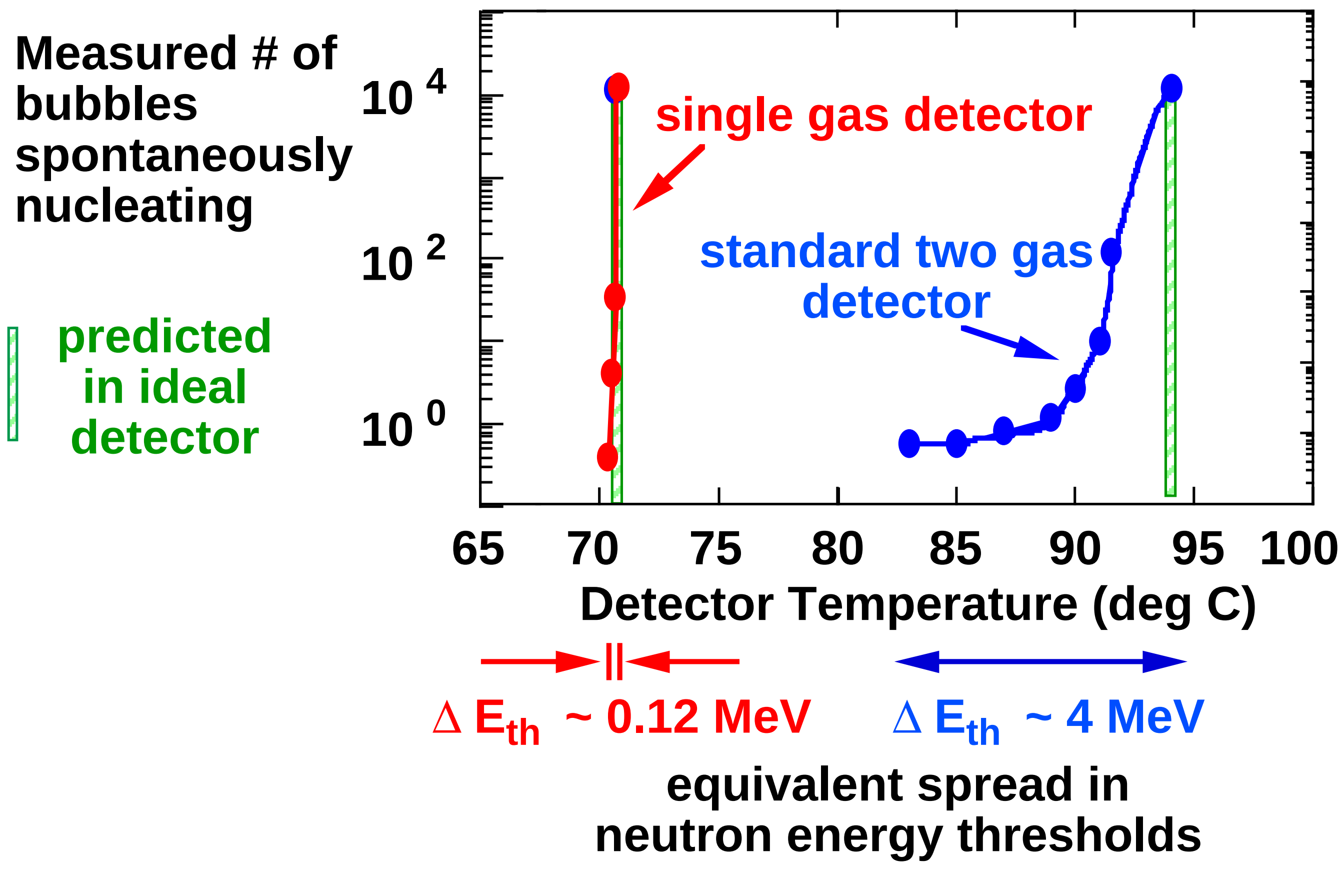
- **Calculated below threshold response in standard two-gas bubble detectors will prevent observation of the alpha knock-on neutron tail**

SINGLE GAS DETECTORS LOOK PROMISING FOR ALPHA KNOCK-ON TAIL MEASUREMENTS

GENERAL ATOMICS

- **Bubble neutron detectors made using a single gas will avoid the below threshold response due to the drop-to-drop variations in the gas mixture**

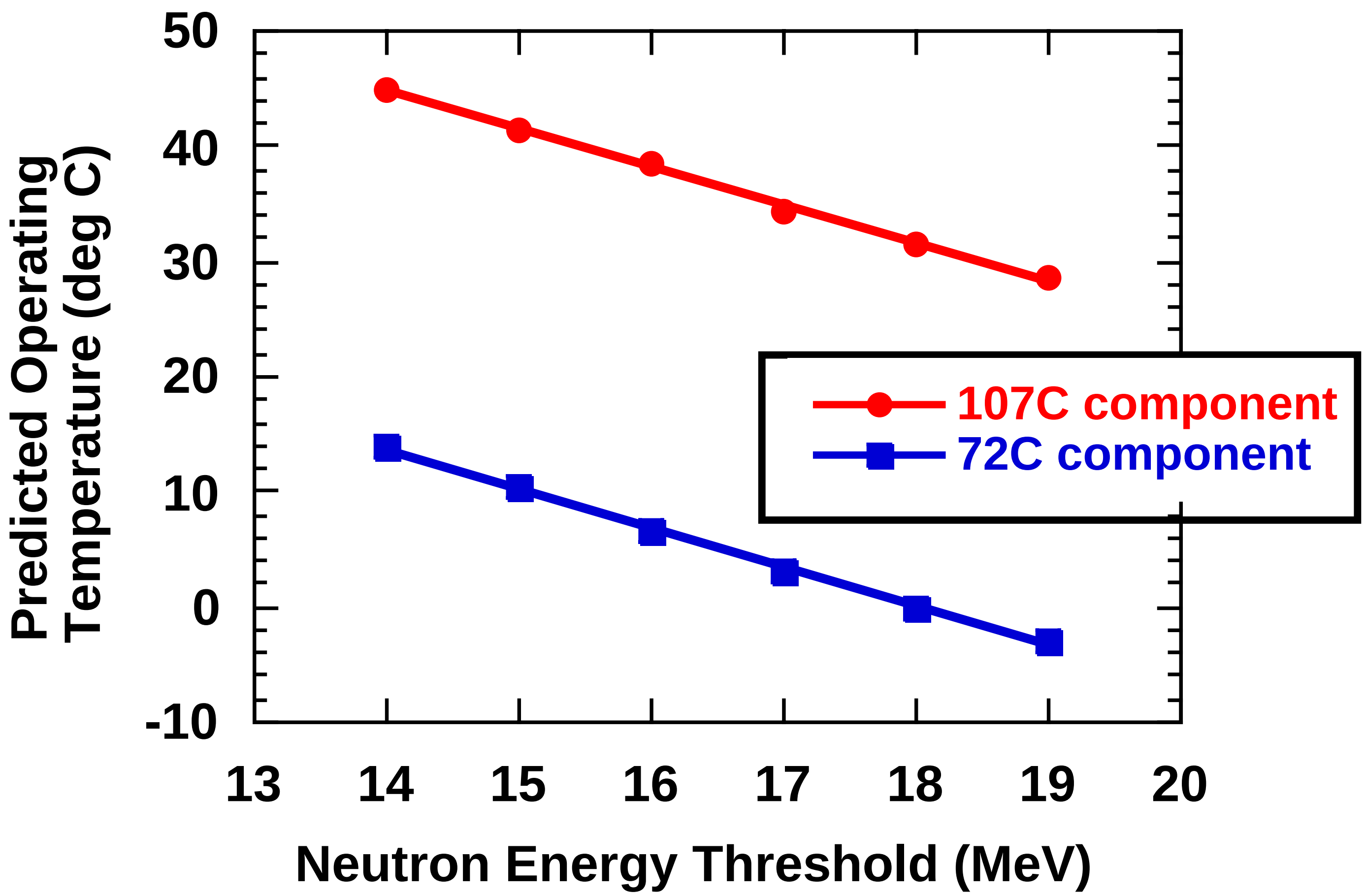
- **Preliminary spontaneous nucleation data on single gas detectors show a much narrower variation in thresholds**



- **Preliminary results show ΔE_{th} ~ 0.12 MeV for single gas detector which is less than the ~ 0.5 MeV required for alpha knock-on measurements**

Single-Gas Detectors Can Be Made From Either Component Used In Standard Detectors

- Changing the neutron energy threshold in a single-gas detector will require changing its operating temperature

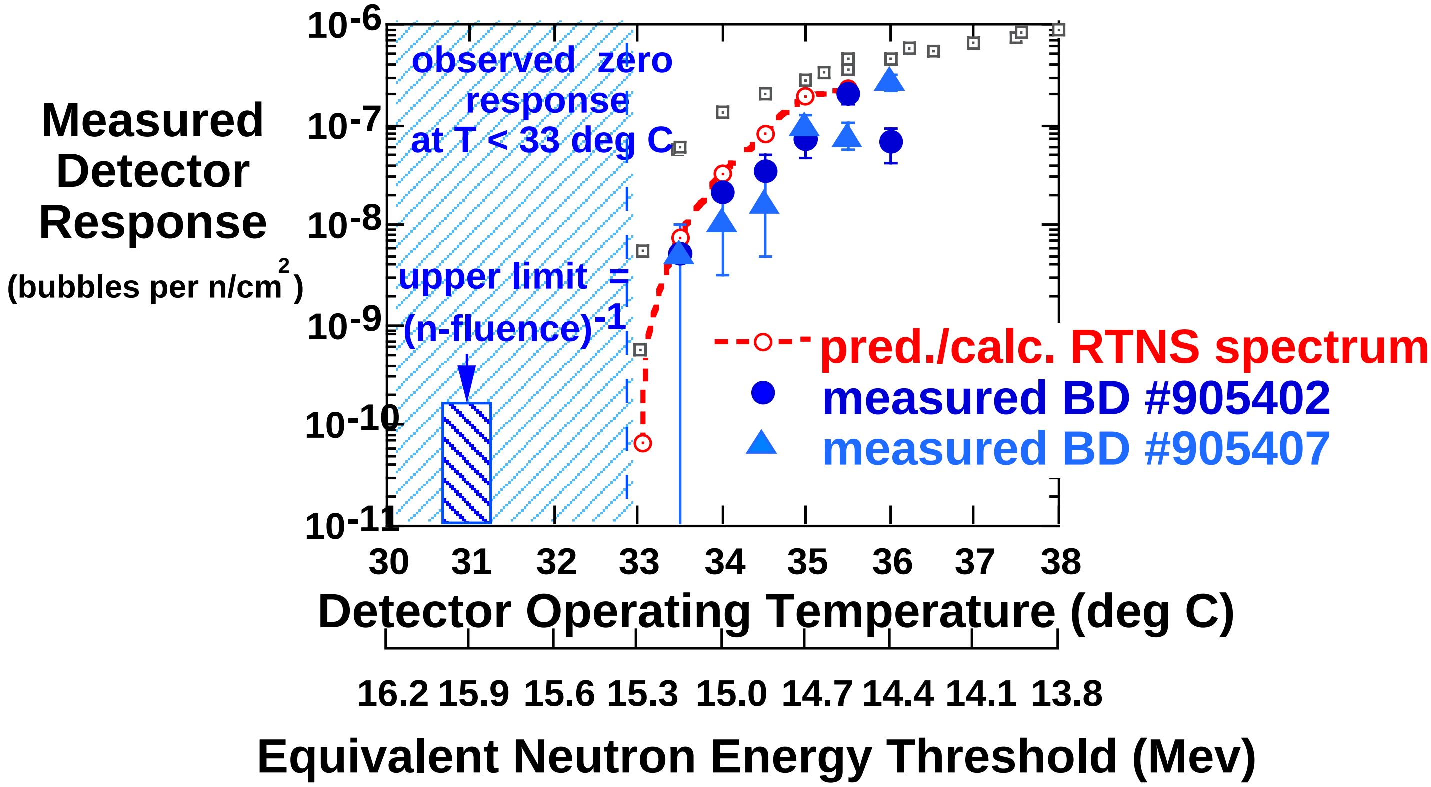


- Initial detectors tested at RTNS made from lower volatility 107C component due to convenient predicted operating temperature range of 30 to 45 deg C

- Measuring the energy spectrum of the alpha knock-on neutron tail will require an array of single-gas detectors operating at different temperatures

Single-gas Detectors Show No Response To Neutrons With Energies Below Threshold

GENERAL ATOMICS



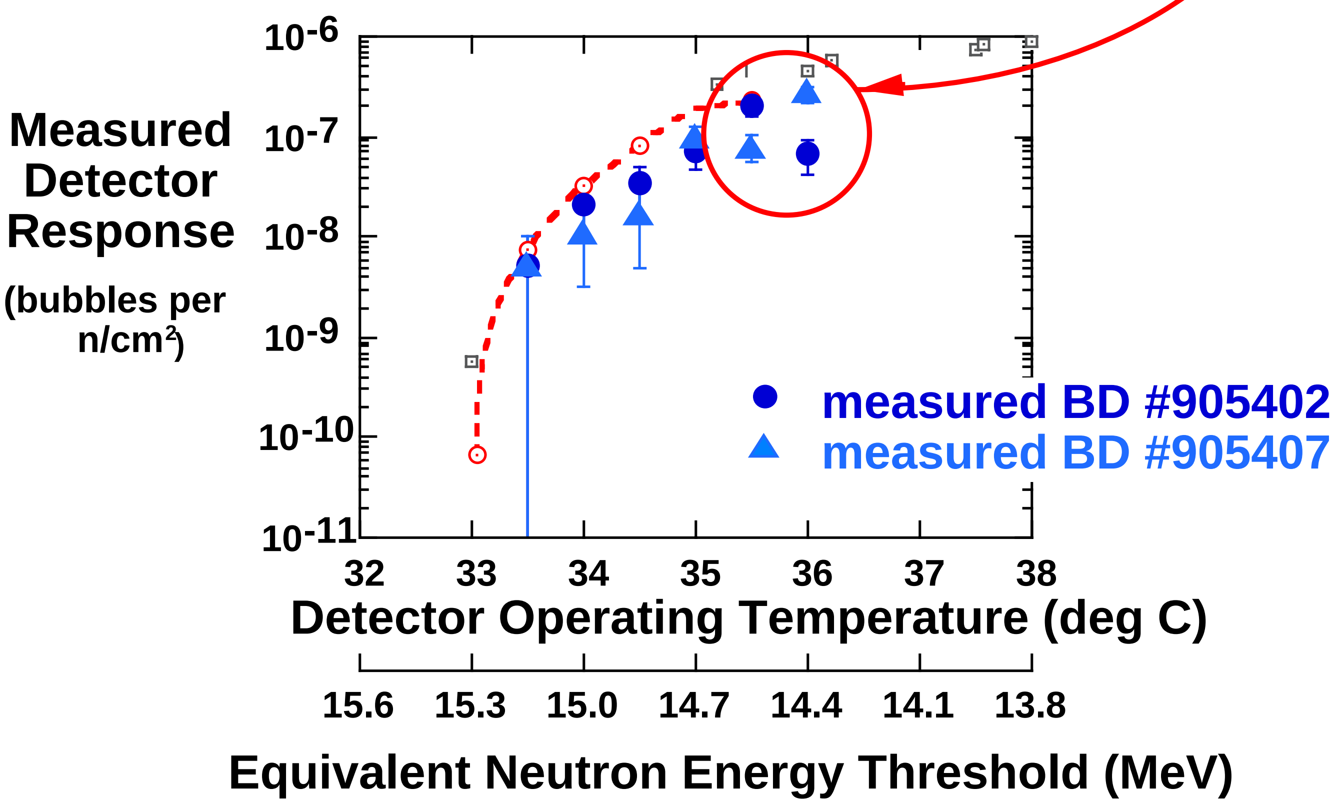
- Consistently observe zero neutron response for all data runs with detector temperatures < 33.5 degrees C.

- Longer exposures at RTNS are planned with the goal of demonstrating that the upper limit = (incident neutron fluence)$^{-1}$ on the response to neutrons with energies below threhold is less than ~10^{-5} of the response at 14 MeV. Measurements of the DT neutron energetic tail induced by alpha particle knock-on collisions will require a below-threshold response (BTR) less than this.

GENERAL ATOMICS

Large Variation Observed In Neutron Response Of Initial Design Single-Gas Detectors

GENERAL ATOMICS



- Two nominally-identical detectors (made using component 107C) sitting side-by-side in constant temperature water bath sometimes showed widely different neutron responses at RTNS, e.g. 7 bubbles in one and 91 in the other

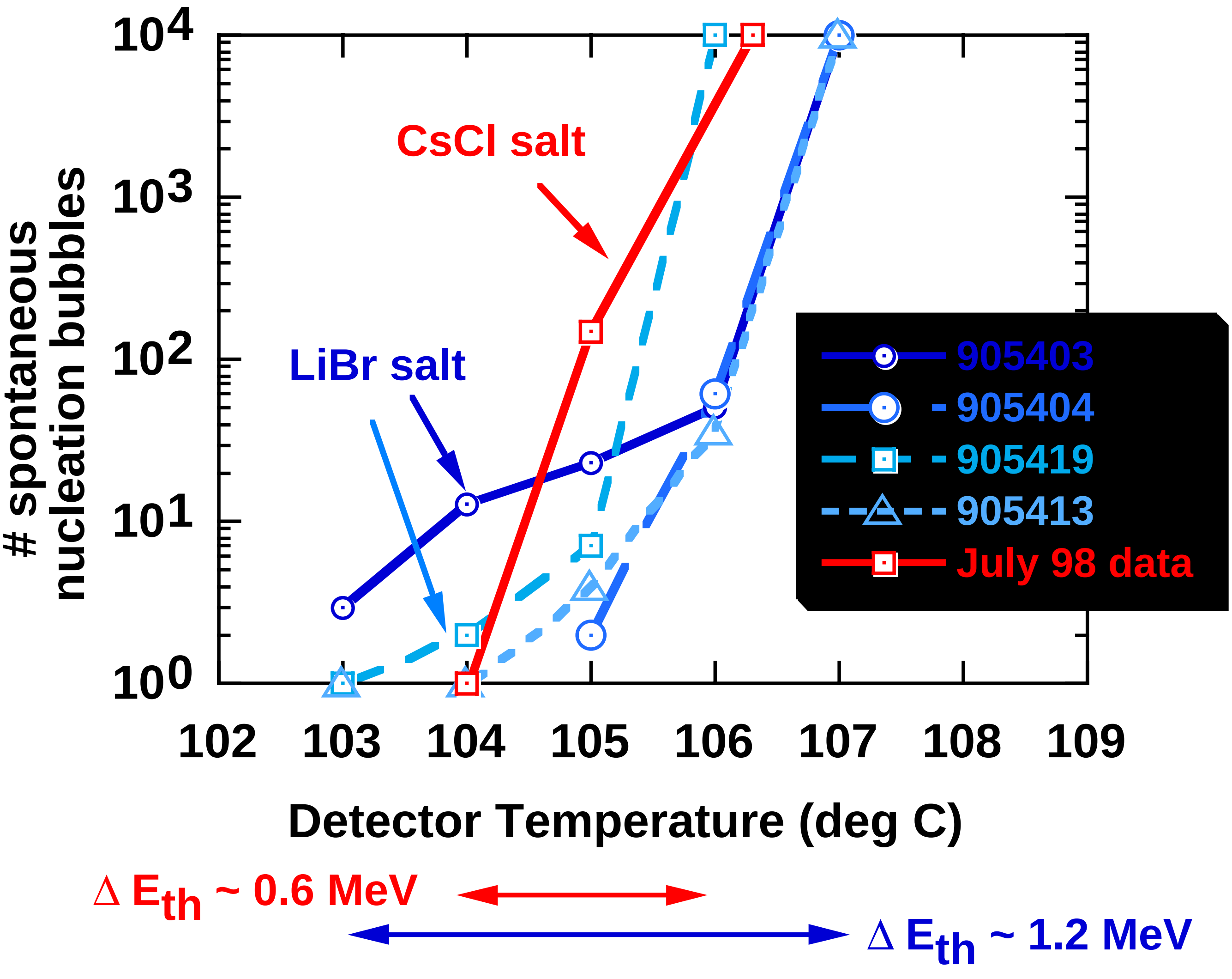
- The reason for this unexpected variation in the neutron response is not completely understood, but recent spontaneous nucleation experiments show that a change in the gel and/or using single-gas detectors made from component 72C should significantly reduce the variation.

GENERAL ATOMICS

Change In Gel Responsible For Variation In Detector Thresholds?

GENERAL ATOMICS

- The recent spontaneous nucleation data on the 107C component detectors shows a much larger variation in thresholds than earlier data

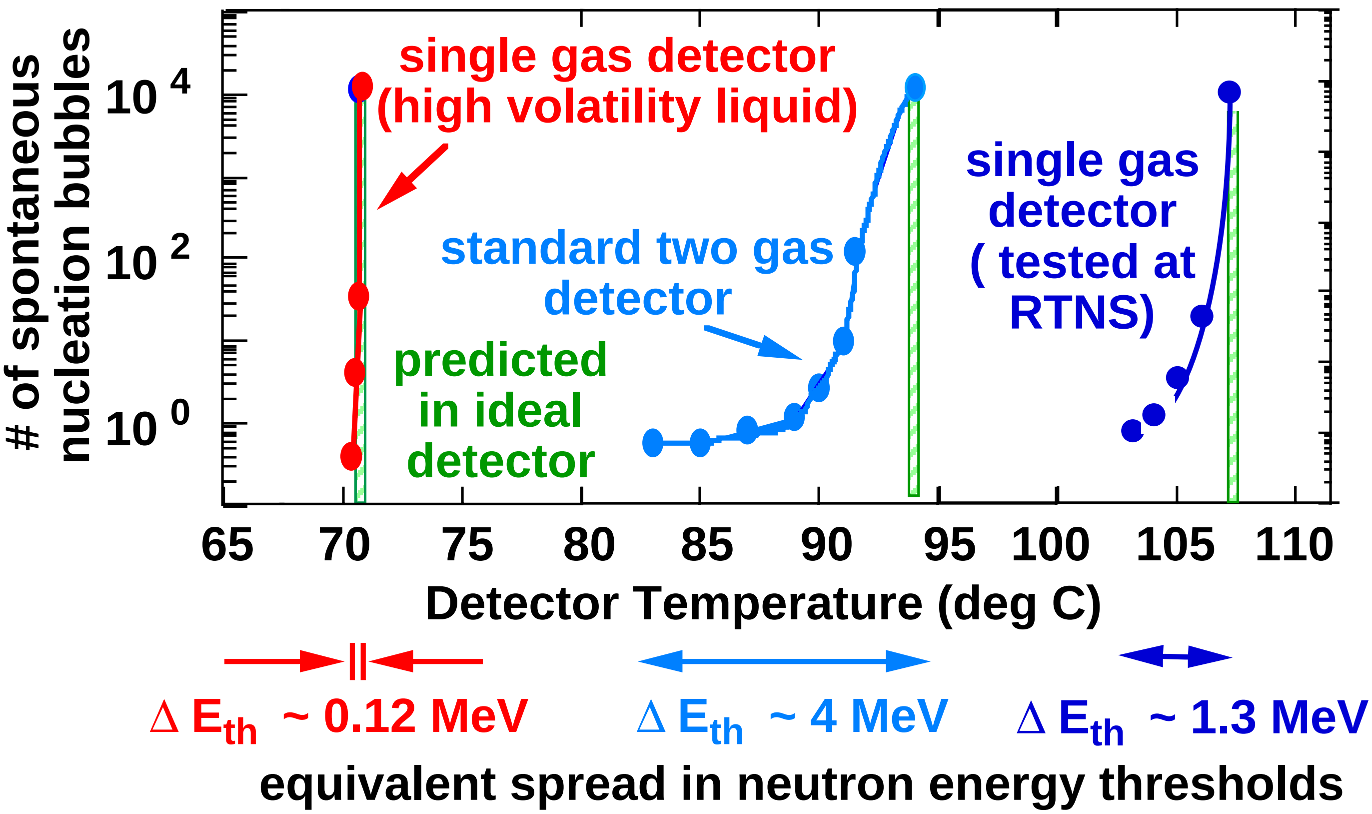


- Recent detectors were made using LiBr salt in support gel to avoid possible below threshold response due to Cl(n, alpha) reactions

- Spontaneous nucleation data will be taken on a larger number of CsCl salt detectors to see if variation in thresholds is definitely < 0.6 MeV (2 deg C).

GENERAL ATOMICS

Detectors Made From Higher Volatility Liquid Show Sharper Energy Threshold



- The single-gas detectors tested on RTNS were made using the higher volatility component of those used in the standard two-gas detectors because of their somewhat more convenient operating temperature (31 deg C @E_{th}=16 MeV versus ~10 deg C for the lower volatility component)

- Single-gas detectors made from the lower volatility component liquid show the narrowest range in spontaneous nucleation temperatures and should have the sharp neutron energy threshold ΔE_{th} less than the ~0.5 MeV required for alpha knock-on measurements

Summary Of Results On Single-Gas Detectors

Results Consistent With Predictions

- **Single-gas BD's do not show the response to neutrons below threshold that rules out the use of standard two-gas detectors for alpha knock-on measurements.**
- **Preliminary measurements of n-response vs. detector operating temperature appear to agree with the predicted detector response.**

Unanticipated Results

- **Initial tests at RTNS of detectors made from higher volatility component show a significant variation in the n-response between nominally identical detectors.**
- **These high volatility component detectors also show variations in their spontaneous nucleation temperatures and hence expected neutron energy thresholds.**

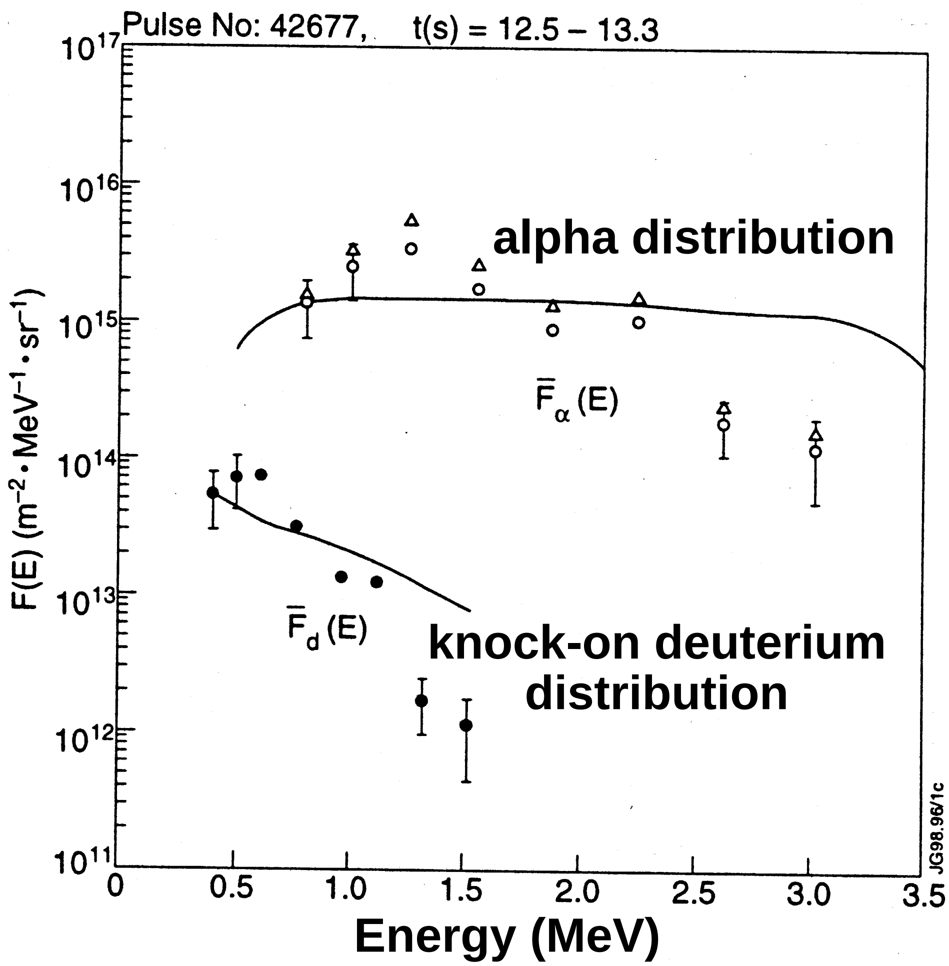
Future Plans

- **Measure the variation in the spontaneous nucleation temperatures of single-gas detectors made from the lower volatility component, followed by neutron response measurements at RTNS to verify predicted lack of below threshold response**
- **Preliminary spontaneous nucleation data shows that single-gas detectors made from the lower volatility component have an energy threshold variation of ~0.12 MeV which is sharper than the ~ 0.5 MeV required for knock-on tail measurements.**
- **Objective is to have bubble neutron detectors characterized and ready for alpha knock-on measurements during JET DTE2 experiments planned for 2002 or later**

Evidence Of Observation Of Alpha Knock-on Tails On JET By Other Diagnostic Techniques

GENERAL ATOMICS

- **In 1994, I proposed using the existing JET neutral particle analyzer to observe energetic neutrals from the alpha-induced knock-on fuel ion tails charge exchanging with hydrogen-like impuritiy ions in JET**



- **During JET experiments to measure the helium neutrals resulting from alphas charge exchanging with impurity ions, there is evidence that the knock-on deuterium ion tail has also been observed. *A.A. Korotkov, et.al. JET-P(98)25 September 1998***

- **Knock-on DT neutron tail has been observed using JET magnetic proton recoil spectrometer (unpublished).**