Development of a recirculating superheated liquid detector for dark matter search

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Introduction

Understanding the nature of dark matter is one of the most important goals in modern astroparticle physics [1]. A leading candidate to explain the dark matter is a relic density of cold, nonbaryonic weakly interacting massive particles or WIMPs, and direct detection dark matter experiments hope to observe the nuclei recoiling from the rare collisions of WIMPs with ordinary matter. Historically, the interaction of dark matter with normal matter has been divided into two categories, spin dependent (SD) and spin independent (SI). The superheated detector technology has been at the forefront of SD searches, and there are two primary types of detectors: bubble chambers and droplet detectors. The superheated detector technology provides a unique approach to direct detection, with excellent rejection of gamma and beta events, excellent alpha rejection using the acoustic emission of bubble formation, and the ability to employ different targets.

In operating bubble chambers a practical issue is the evaporation of the liquid upon formation of bubbles. Conventional recovery relies on pressure cycles. Re-pressurizing however leads to discontinuous operations and requires non-trivial setups. In this work, we are proposing an alternative scheme to run the detector continuously by condensing the bubbles created by the nucleation in the superheated liquid. A small version of the chamber has already been built and tested with ^{252}Cf neutron source and for the background radiation. The details of the design of the detector, thermal simulation and the measurement with neutron sources are presented in this article.

The detector setup

The chamber consists of multiple connected

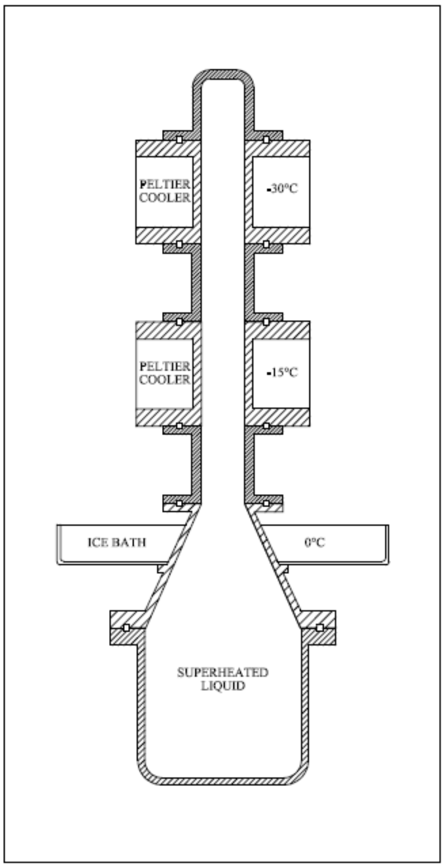

Fig. 1: Schematic of the detector setup

temperature volumes as shown in Fig.1. The bottom most volume is the main detector volume (DV). The top most volume is the condenser volume (CV), and the intermediate volumes maintain a smooth temperature gradient. The DV must be maintained at 25^{o}C and the CV is at -30^{o}C to condense the bubbles to liquid, R134a ($C_2H_2F_4$; b.p. -26^{o}C). Each volume is thermally tied to temperature stages spanning -30^{o}C to ~25^{o}C.

In the earlier version, the whole volume sits inside a machined copper block, with an extended cold finger dipped into a liquid nitrogen (LN2) dewar. The copper block also had 8 heaters, and silicon diode temperature sensors to monitor the temperature and provide the appropriate amount of heating power.

In the modified present version, the container is made of perspex and the constant temperature parts are surrounded by stainless steel blocks (AISI304) with the intermediate spaces covered by insulators. The shape of the detector system has also been modified to control the convection inside the volume.

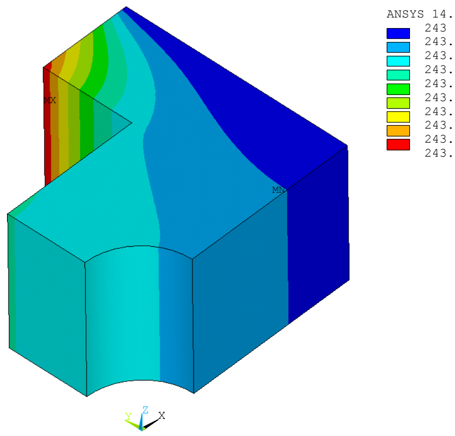

Fig.2. Temperature distribution in one-eighth symmetrical block of AISI 304 (Temperature in Kelvin)

Results and Discussion

Steady state thermal analysis was carried out in Multi-physics finite element software ANSYS. Owing to the symmetrical nature of the model, one-eighth portion of the system was modeled. Heat flow to the system from ambient was considered through radiation and natural convection of air. The cold plates of peltier coolers attached at the sides of the AISI 304 block act as cold sink as they were maintained at -30°C at the junctions through the internal control system. The temperature distribution in the AISI 304 block is shown in Fig. 2. The temperature gradient along the region of interest, the central hole, is about 0.2°C.

The detector has already been developed with one cooling part at temperature ~0^{o}C. The sensitive liquid is R114 ($C_2Cl_2F_4$; b.p. 3.7^{o}C) and the buffer liquid is triton-X100. The cooling was done using ice-salt mixture.

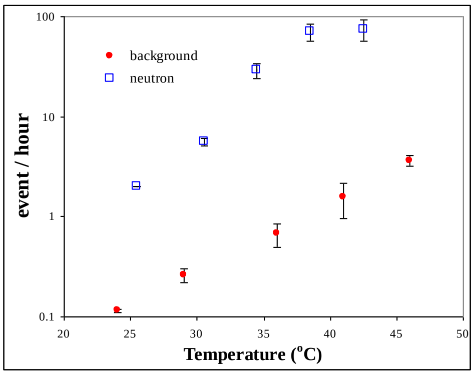

Fig.3. Response to ^{252}Cf neutrons and background radiation.

The bubble nucleation is observed in presence of ^{252}Cf neutron source and also for the background radiation as shown in Fig.3 by varying the operating temperature. The complete cycle of condensation back to the liquid from vapour bubble is observed and the pressure recovery is measured to be within five seconds from the beginning of bubble formation.

References

1. Dark Matter Search Results from the PICO-2L C3F8 Bubble Chamber, PICO Collaboration, Phys. Rev. Lett.144, 231302 (2015).