Report for Sigma Pi Sigma Undergraduate Research Reward

Studies of a Pyroelectric Crystal to Develop a Tabletop Neutron Source

Indiana University

Society of Physics Students

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Abstract

This report summarizes progress on the development of a neutron source from an existing commercial product. The targeted tabletop device uses a pyroelectric crystal to create an electric field that accelerates deuterium ions towards a deuterated target to produce neutrons via fusion. A pyroelectric X-ray generator was characterized and its performance successfully compared with the manufacturer's specifications. A second special "opened" device was obtained from the vendor. A vacuum chamber in which to operate this device in a partial vacuum (and then later with deuterated gas) has been designed and is currently being fabricated. The project will continue next semester with the completed vacuum chamber and the conversion of the pyroelectric X-ray generator to a pyrofusion neutron generator. The neutrons will be characterized and used to further study particle interactions by Indiana University undergraduate students.

Review of Project

Pyroelectricity is the ability of certain materials to generate an electrical potential when they are heated or cooled. A research paper [1] was published in *Nature* in mid-2005 about an experiment that used a pyroelectric crystal to achieve nuclear fusion. Pyroelectric fusion is the process by which a pyroelectric crystal in a vacuum is cooled down and then slowly heated. Due to the properties of the pyroelectric crystal, the heat generates an electric potential and creates an electric field. In the original experiment, a copper disk was mounted on the crystal and then a tungsten needle [2] was attached to the disk. These two components allowed an electric field of gigavolts per meter to be magnified at the very tip of the tungsten probe. With gaseous deuterium atoms in the chamber, enough of the atoms became ionized and accelerated toward the deuterated target to produce approximately 1000 fusion reactions every second via the process

$$D + D \rightarrow {}^{3}\text{He (820 keV)} + n \text{ (2.45 MeV)}.$$

It is proposed to attempt to convert a commercial product meant for generating X-rays into a small tabletop pyroelectric fusion device that will also provide a tabletop source of high-energy neutrons for other experiments.

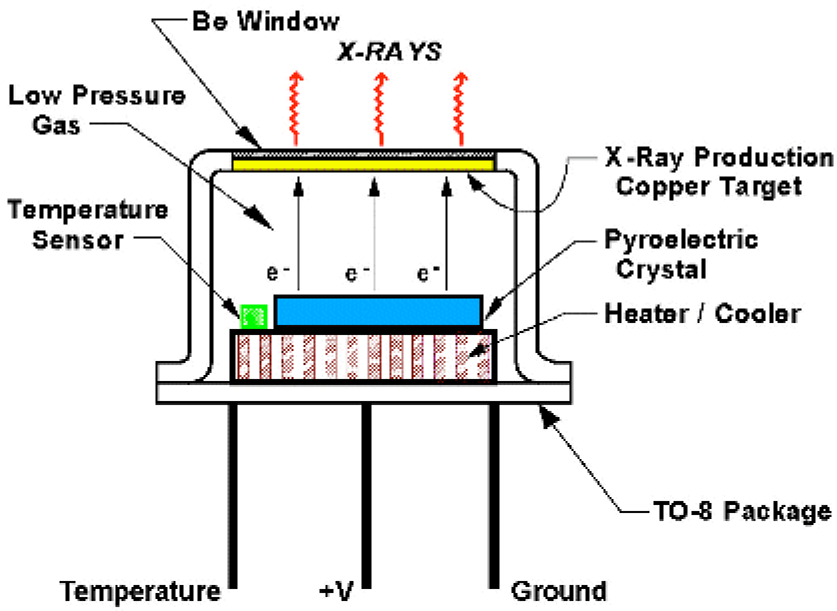

Figure 1. This is the COOL-X device in its original form before conversion begins [4].

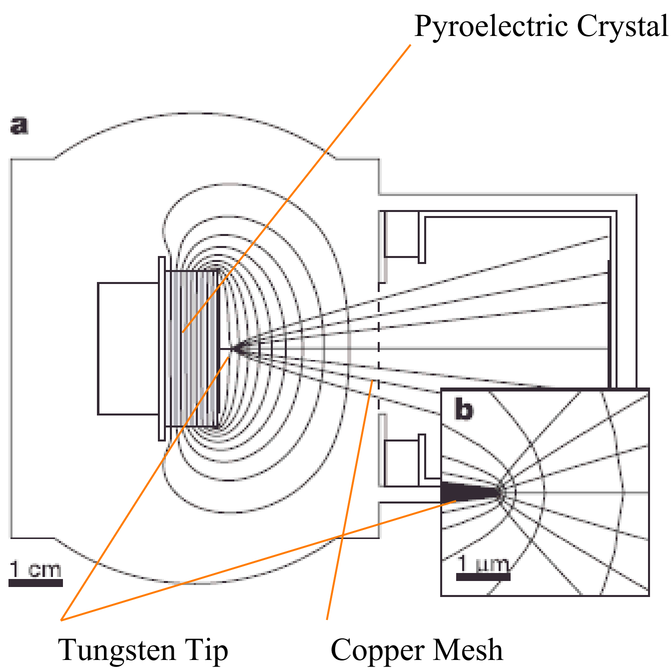

Figure 2. Arrangement of pyroelectric fusion device in *Nature* article [1]. Very similar to how the final product of the conversion of COOL-X will look.

Current Progress

Before trying to achieve pyrofusion, a commercial X-ray generator, COOL-X [4], was first acquired that accelerates electrons using pyroelectricity instead of deuterons. Initial work consisted of characterizing the pyroelectric and X-ray generation capabilities of the device, and comparing it to the manufacturer's specifications. The device operates by heating then cooling the pyroelectric crystal, which is defined as one cycle. During the heating phase the device produces a non-constant flux of electrons and then produces no electrons during the cooling phase. Measurements were taken using a photomultiplier tube to count the number of x-rays one cycle at a time.

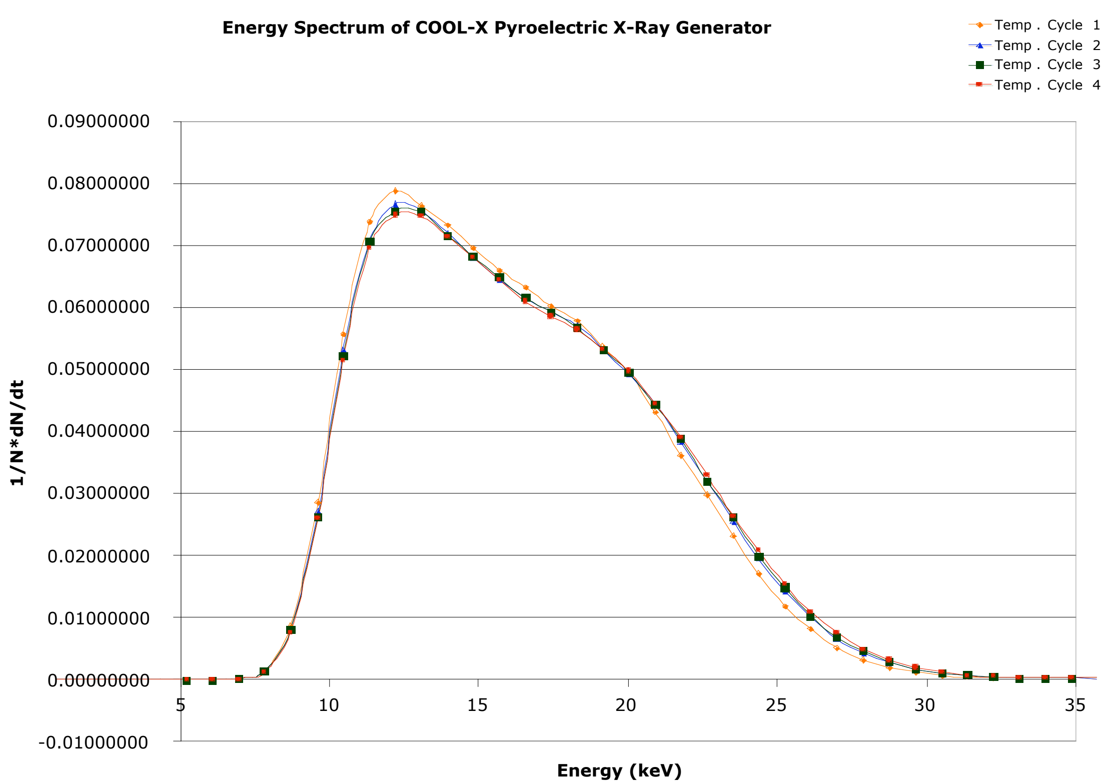

Figure 1 shows the energy spectrum of all four trials proportional to the total number of X-rays counted in each trial. This shows that there are a consistent number of x-rays at each energy level in each trial.

The resolution of the X-ray detector above was not sufficient to determine if the COOL-X device produced the two X-ray peaks specified by the manufacturer. A higher precision X-ray cryogenic solid-state detector was loaned by Professor David Baxter at Indiana University, which showed the expected two distinct X-ray energy peaks as shown in Fig. 2. This procedure also was very useful since the well known energy of the copper characteristic X-rays allowed a very precise energy calibration.

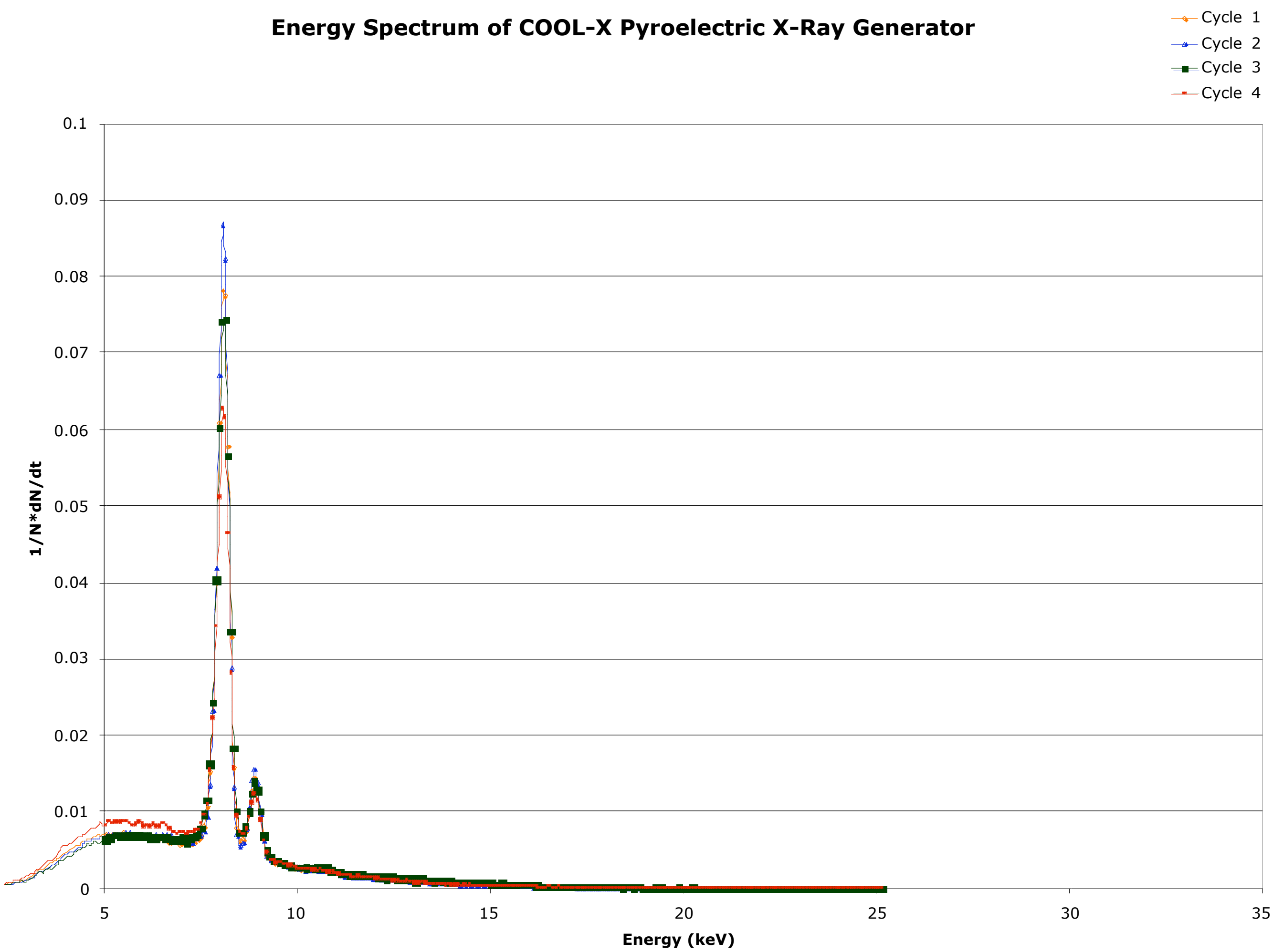

Figure 2 is the data taken from the high precision X-ray detector provided by Professor David Baxter. This higher precision shows two peaks at energy levels, 8.0493 and 8.8996 keV, equivalent to two known specific copper x-rays.

Using this energy calibration, the cut-off energy of the X-ray spectra observed is approximately 35 keV, as shown in Fig. 1, in agreement with the manufacturer's specifications. This upper bound on the energy is a result of the limited electric field available for acceleration of electrons that impinge on the Beryllium window, subsequently generating electrons. This upper energy limit will have to be increased to be able exceed the threshold energy for the D-D reaction for achieving fusion.

The alteration of the COOL-X was proposed to begin by cutting open the device; however, the lead project engineer [3] of the device at Amptek warned of a high probability of destroying the device in the process. The vendor provided a second device, already opened, free of charge that will be used for the neutrons thereby leaving the original X-ray generator intact.

The internal atmosphere of the device is at a partial air vacuum of 50–200 mTorr; the pyroelectric field ionizes these air molecules and subsequently accelerates them towards a target. The opened device therefore needs to be operated in a larger vacuum chamber. A basic vacuum chamber roughly 35 cm long has now been obtained and the necessary alterations designed. The departmental machine shop is currently working on the fabrication and alterations.

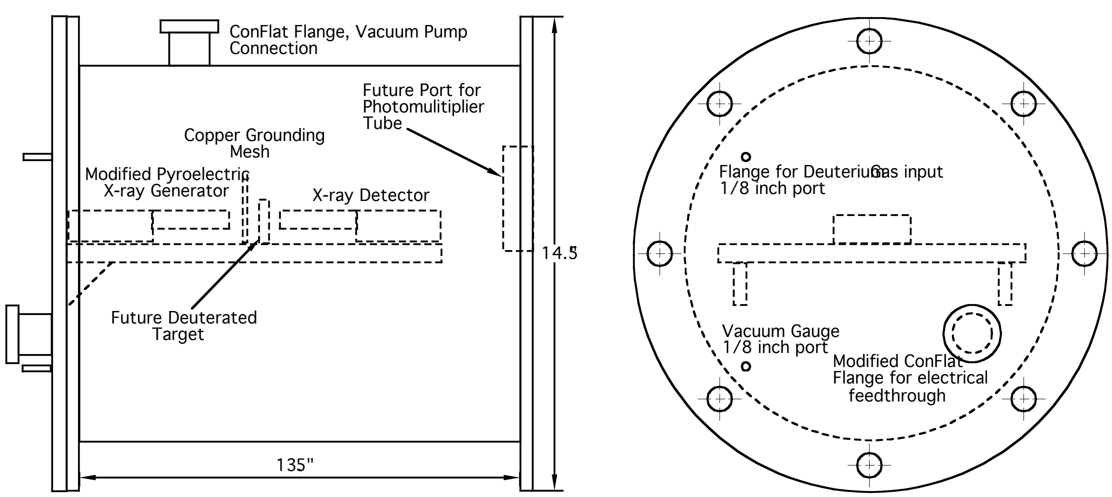

Figure 3: Experimental layout in custom vacuum chamber.

Figure 3 shows the layout of the vacuum chamber that will house the experiment.

Further Planned Research Work

When the vacuum chamber alterations are complete, the device will be mounted in the vacuum chamber, and device functionality will be re-established. The voltage applied to the device will be reversed to determine if positively charged ions of a gas in the chamber can be made to accelerate in the direction of the target area. Signals from a plastic scintillator target coupled to a phototube in coincidence with current from the electrons flowing back to the crystal will confirm successful acceleration of positive ions. The energy spectrum of the accelerated ions will be detected and compared with spectrum of the device when not in a vacuum. After verifying the device's functionality, the alteration of the COOL-X device can begin.

A copper disk will then be mounted on the pyroelectric crystal and a tungsten tip [3] will be attached to the copper disk to greatly increase the electric field value and enhance acceleration of positively charged ions from the tip. The particle energy spectrum will again be measured and characterized as a function of accelerating voltage and temperature of the pyroelectric crystal. When every step has been accomplished successfully, the chamber will be filled with deuterium gas and a deuterized plastic scintillator will be placed such that the accelerated deuterium collides with the target. Finally, a neutron detector will be used to verify that pyroelectric fusion reactions have occurred. The device will then be used to compliment another project at Indiana University, a tabletop monoenergetic electron source, as a particle interactions research tool for undergraduate students.

Project Budget and Expenditures

Table 1: Project budget and expenditures.

Item	*Budget*	*Expenditure*	*"Matching" Funds, Dept. of Physics*
5 Tungsten Probes	$150	–	$150 (future)
Bicron BC-436 plastic scintillator	$100	–	Provided, on loan†
Burle C31016H 1" Photomultiplier module	$425	–	Provided, on loan†
Custom design aluminum vacuum enclosure	$225	–	Modifying existing chamber
Vacuum ancillary equipment	$100	–	$250
AmpTek COOL-X pyroelectric X-ray generator	$1970	$1970	$530 (actual cost $2500)
Opened COOL-X device	–	–	Free of charge from vendor
XR-100CR X-Ray Detector with Si-PIN	–	$2950	$2950
PX2CR Power Supply and Amplifier for XR-100CR	–	$2150	$2150
Balance	**$0**		

†Scintillator & PMT, high voltage supply, oscilloscope, computerized DAQ with Multi-channel ADC provided by Dept. of Physics on loan.

References

[1] B. Naranjo, J.K. Gimzewski and S. Putterman, *Observation of nuclear fusion driven by a pyroelectric crystal*, Nature **434**, 1115 (28 April 2005).

[2] Kentax UHVEquipment, Seelze, Germany, tunneling tips, <http://www.kentax.de/>.

[3] Personal communication, John Pantazis, jpantazis@amptek.com.

[4] Amptek Inc.,Bedford, MA 01730 U.S.A., Miniature X-Ray Generator with Pyroelectric Crystal, <http://www.amptek.com/coolx.html>.