Results of Beam Window Safety Research

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1 Introduction

The Jefferson Lab Hall A experiment E02-013 (GEN) will use a high pressure ^{3}He glass cell as target. As the target cell is located between two beam windows, tests must be performed to ensure the safety of these windows even in the case of a rupturing cell.

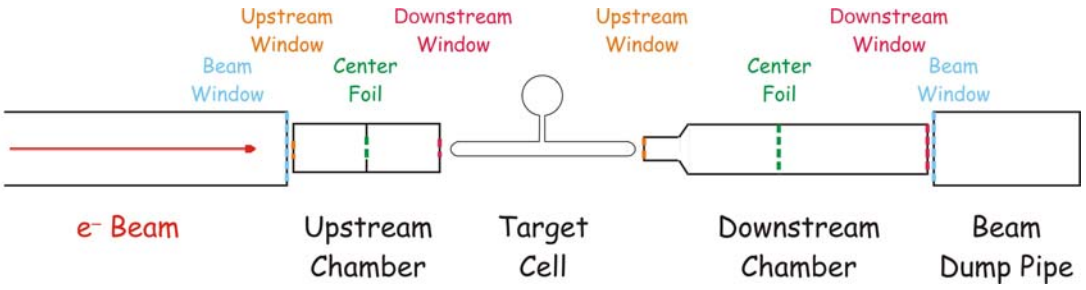
Several beam window safety tests have been done in the polarized target lab of the College of William and Mary. The tests in September 2005 were done with a similar but improved set-up compared to the tests in December 2003. The latest tests have the goal to ensure the safety of the beam line exit windows in case of a rupturing cell and to minimize the amount of material between the target cell and each beam window.

2 Experiments

2.1 Experimental Setup

Instead of using a filled target cell that can be used in Hall A the cell explosion tests are performed with dummy cells that are specially designed for rupture tests. These dummy cells consist of a target chamber with a gas inlet which is connected to a ^{4}He supply. The most obvious difference though between a target cell and a dummy is that the spherical pumping chamber is not required for the rupture tests. Contrary to a target cell, the target chamber of a dummy has a thin end window only on one side.

To prevent damage of both beam windows in Hall A an upstream explosion chamber will be placed behind the beam line and its upstream beam window. This set-up will be followed by the target cell, a downstream explosion chamber and the beam window of the beam dump pipe.



The beam line exit window in Hall A consists of a thin beryllium foil which is substituted in the explosion tests by a 2 mil aluminum foil because of the environmental and safety concerns when handling beryllium.

The rupture tests in the polarized target lab are split up in two rounds: The first round of tests analyzes the performance of the upstream explosion chamber and the second one analyzes the behavior of the downstream chamber. In both test rounds the dummy cell is filled with helium at high pressure which ensures that the dummy is under comparable conditions to a target cell which is filled with helium up to a pressure of 12 atmospheres.

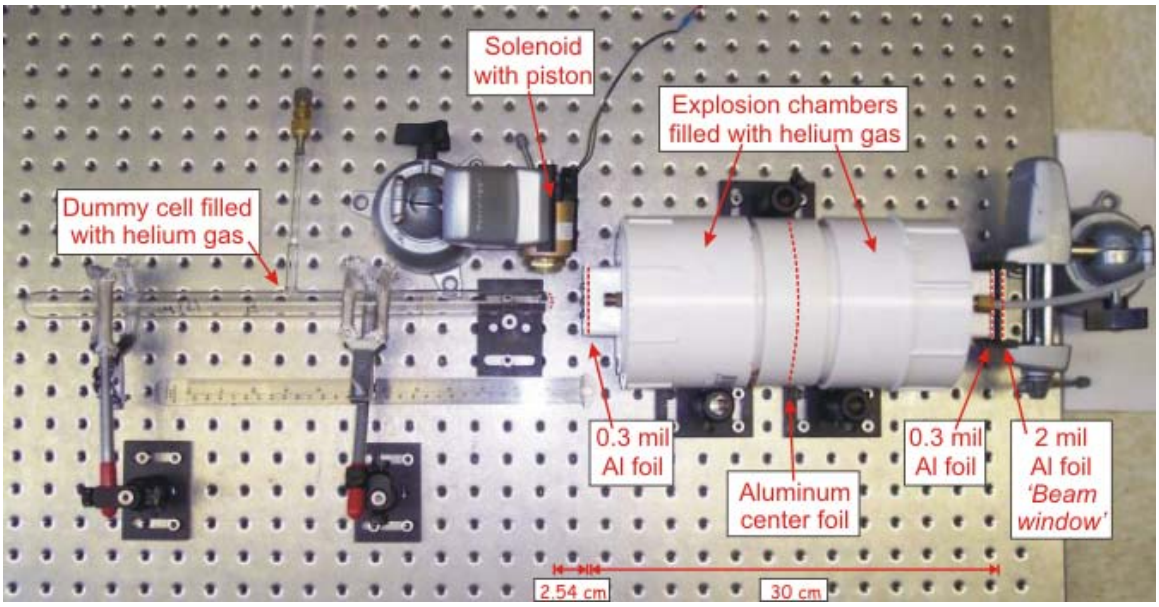
Both explosion chambers are built out of PVC pipes and have an 8 micron (~0.3 mil) aluminum foil 1 inch away from the thin glass window of the cell and also an 8 micron aluminum foil ¼ inch in front of the 'beam window'. In the middle of the chamber an aluminum foil is mounted that stops all glass bits from passing through the whole chamber. A ^{4}He gas inlet on one side of the chamber, a small hole in the frame of the center foil and an outlet on the other side of the chamber assure a low gas flow through the complete chamber. The helium helps to minimize the radiation loss of the beam as the radiation length of helium is larger than the one of air.

To rupture a dummy cell a solenoid-driven piston hits the thin window of the cell. The glass breaks, in the same moment the target cell explodes and a jet of gas and small glass pieces hits the first window of the explosion chamber, blows it out and the gas diffuses within the expansion chamber.

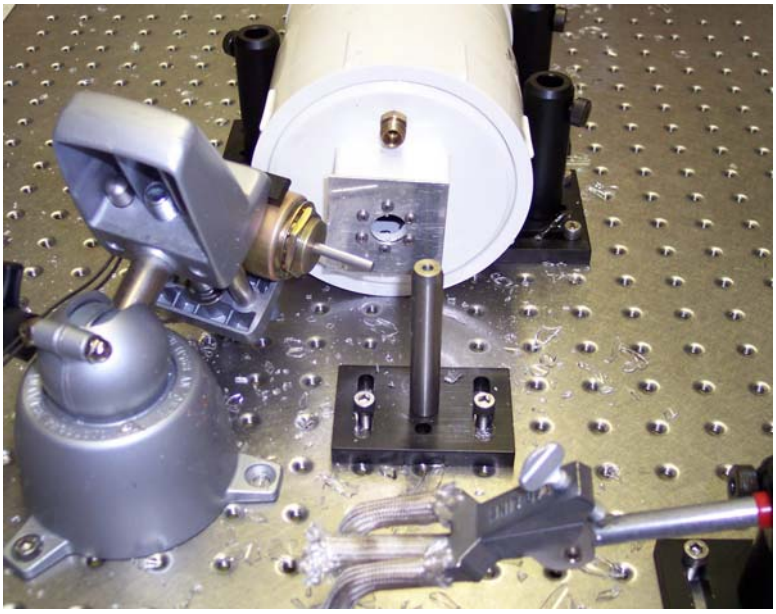
The length and diameter of the chambers, the diameter of the window foils and also the thickness of the center window foil differ in the two test rounds.

2.2 First Round of Tests: Upstream explosion chamber

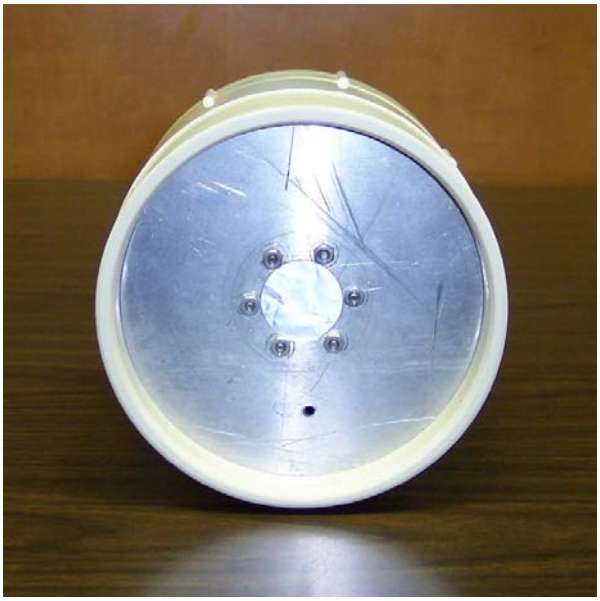
In the first round of tests the upstream explosion chamber with an inner diameter of 10.2 cm is used. The distance between the upstream window foil (in this picture on the right side of the explosion chamber) and downstream window foil (seen on the left of the chamber) is 30 cm. The diameter of both outer windows is 1.6 cm; the diameter of the center foil is 2.6 cm.



Four dummy cells which were ordered from the same glass blower who produces the cells that are used in Hall A, and one cell that was left over from the rupture tests in 2003, were used in this portion of the test. The results of these five tests can be found in the table on page 4. The pressure that is mentioned is the pressure of the ^{4}He gas in the dummy cell. The aluminum foil used as center window had a thickness of 1 mil.



Most of the cells ruptured when the piston hit the cell window the first time. Only two cells did not explode during the first attempt but needed several attempts. All cells exploded catastrophically, means the complete target chamber burst into little pieces as can be seen on the photo on the left. It shows also the frame of the downstream window; the foil was blown out completely.



This photo shows the center window foil and frame inside the upstream explosion chamber.

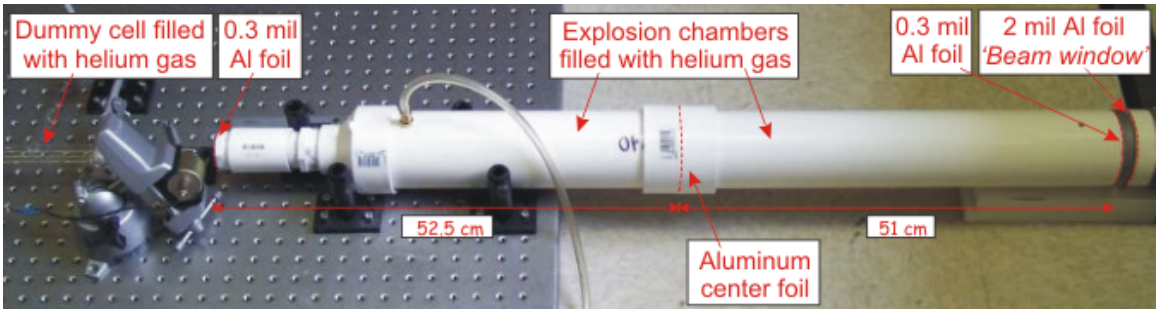
Table of upstream chamber test results:

Date	1st order, dummy cell	Window thickness	Pressure	0.3 mil downstream window	1 mil center window	0.3 mil upstream window	2 mil beam window
7/21/05	Old dummy cell	unknown	145 psig**	Blown out completely	Many small pinholes	Intact	Intact
7/25/05	# 1	147 μm	160 psig*	Blown out completely	Small indentations	Intact	Intact
7/25/05	# 2	140 μm	160 psig*	Blown out completely	Small indentations	Intact	Intact
7/27/05	# 4	133 μm	160 psig*	Blown out completely	Several pinholes and 4 larger holes, the biggest one is 1x1 mm	One small hole	One small inden-tation
7/29/05	# 3	157 μm	160 psig*	Blown out completely	Some very small indentations	Intact	Intact

* 160 psig = 175 psia ~ 11.9 atm
** 145 psig = 160 psia ~ 10.9 atm

2.3 Second Round of Tests: Downstream explosion chamber

The downstream explosion chamber is 103.5 cm long and consists of the following parts: The upstream window with a diameter of 3.6 cm is followed by a 13.6 cm long tube with an inner diameter of 3.6 cm which expands into a bigger pipe with an inner diameter of 7.7 cm. At a distance of 52.2 cm from the upstream window a 2 mil aluminum foil with a diameter of 6.3 cm was inserted that serves as the center window. After another 51 cm the chamber is completed with the 0.3 mil downstream window which has a diameter of 7.7 cm.



Five new dummy cells were ordered for this test round. The gas inlet of cell # 4 broke during its installation. Furthermore, it turned out to be difficult to cause cell # 3 to rupture. In the end this one and the three other dummies exploded catastrophically.

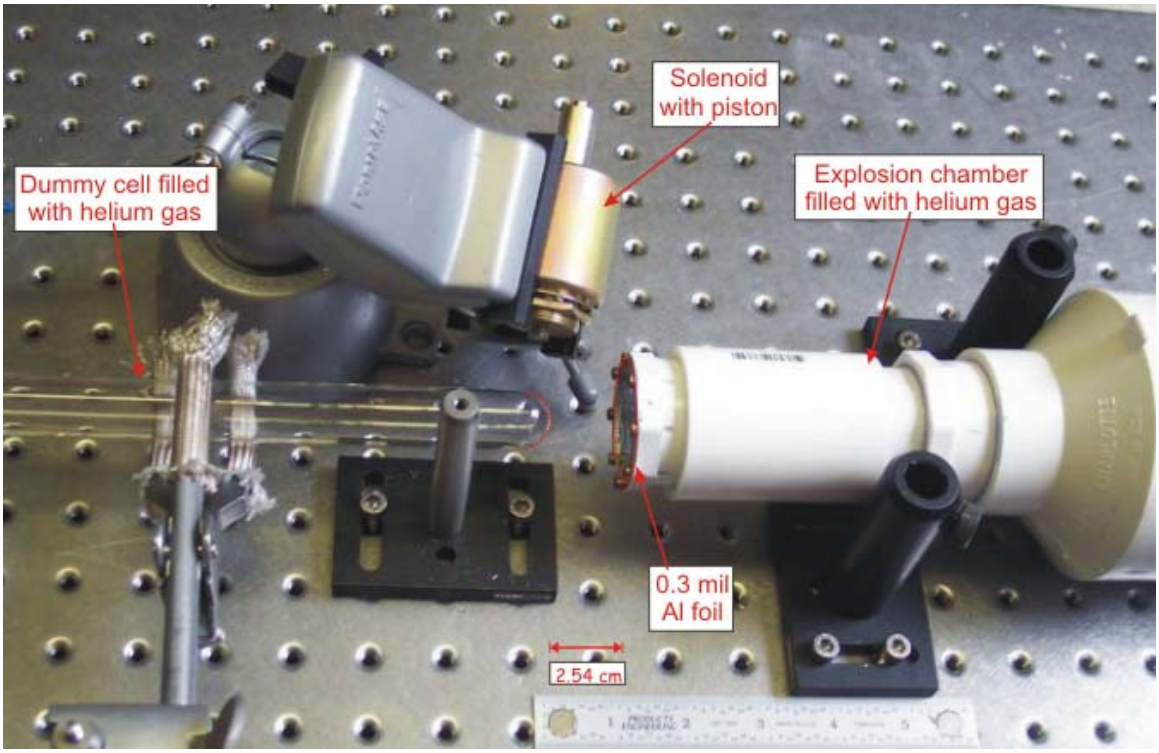


Table of downstream chamber test results:

Date	2nd order, dummy cell	Pressure	0.3 mil upstream window	1 mil center window	0.3 mil downstream window	2 mil beam window
8/29/05	# 4	Thin connection glass tube broke during installation				
8/31/05	# 5	160 psig*	Blown out completely	Several small indentations	Intact	Intact
8/31/05	# 2	160 psig*	Blown out completely	Small indentations	Intact	Intact
9/13/05	# 3	160 psig*	Blown out completely	Several indentations and two pinholes	Intact	Intact
9/14/05	# 1	160 psig*	Blown out completely	Many small indentations and two small holes	Two pinholes next to each other	Intact

* 160 psig = 175 psia ~ 11.9 atm

3 Results

The first set-up with the upstream explosion chamber was tested four out of five times successfully. In one test a small glass bit hit the beam window and caused a small indentation. Therefore this test was not successful.
To ensure that the upstream beam window stays completely intact even if a target cell should rupture, the center foil with a thickness of 1 mil must be substituted by a 2 mil thick foil. This set-up was already successfully tested in the year 2003. The upstream chamber with a 2 mil aluminum center foil has a total radiation length of $7.4 * 10^{-4}$ X_0.

As the downstream beam window of the downstream explosion chamber is still intact after all rupture tests, the second set-up can be considered as a full success and therefore be used without changes. The downstream chamber has a total radiation length of $1.8 * 10^{-4}$ X_0.