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Conceptual Engineering Method for Attenuating He Ion Interactions on First Wall Components in the Fusion Test Facility (FTF) Employing a Low-Pressure Noble Gas

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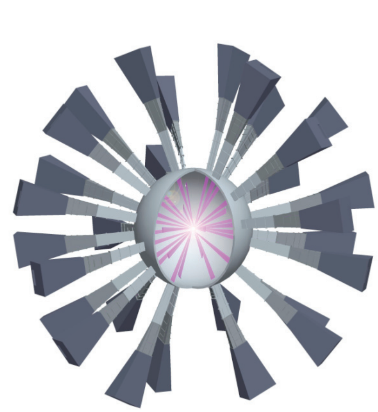
***Abstract*—It has been shown that post detonation energetic helium ions can drastically reduce the useful life of the (dry) first wall of an IFE reactor due to the accumulation of implanted helium. For the purpose of attenuating energetic helium ions from interacting with first wall components in the Fusion Test Facility (FTF) target chamber, several concepts have been advanced. These include magnetic intervention (MI), deployment of a dynamically moving first wall, use of a sacrificial shroud, designing the target chamber large enough to mitigate the damage caused by He ions on the target chamber wall, and the use of a low pressure noble gas resident in the target chamber during pulse power operations. It is proposed that employing a low-pressure (~ 1 torr equivalent) noble gas in the target chamber will thermalize energetic helium ions prior to interaction with the wall. The principle benefit of this concept is the simplicity of the design and the utilization of (modified) existing technologies for pumping and processing the noble ambient gas. Although the gas load in the system would be increased over other proposed methods, the use of a "gas shield" may provide a cost effective method of greatly extending the first wall of the target chamber. An engineering study has been initiated to investigate conceptual engineering methods for implementing a viable gas shield strategy in the FTF.**

Keywords - Laser Fusion, Direct Drive, First Wall, Shield Gas

I. INTRODUCTION

Experimental studies at the Nike have indicated that a low pressure (noble) ambient gas resident in the target chamber during laser pulsing does not appear to impair the ability of laser light from illuminating targets {1}. In addition current investigations into delivering, maintaining, and processing such low pressure gas appears to be viable with (slightly modified) current pumping and plasma exhaust processing technologies. An engineering study is underway to develop a conceptual design for such a system. Employment of a gas fill solution for protecting the dry wall target chamber in the FTF may greatly reduce or possibly eliminate the use of other attenuating technologies designed for keeping He ions form implanting in first wall structures and components [2]. The gas fill concept appears to provide an effective means of extending the life of the first wall while employing mostly commercial off the shelf (COTS) technologies. Although a gas fill configuration may provide a methodology for attenuating damage inflicted on target chamber surfaces, issues associated with target injection (due to heating) need to be further analyzed to ensure that the gas fill concept is viable in the integrated FTF design. A current engineering scoping study indicates that a gas fill solution in concert with other intervention methods (employing a reduced magnetic intervention configuration) or as a stand alone sub-system may provide the protection required to increase the life of the first wall. In this initial operating scenario a heated noble (Ar) gas radiates out to the first wall where it is partially cooled by a first wall cooling system. The gas is then pumped through forty laser ports by two 5,000 l/s turbo molecular-drag pumps (TM-DP) per laser port. For the purpose of reducing organic based lubricants and seals a magnetically levitated TM-DP is being investigated. Currently magnetically levitated turbo molecular pumps are commercially available. The pumps for this proposed application will need to be radiation hardened and fitted with metal seals, which is not beyond the current state of the art for such devices. In this operational mode ambient gas temperatures are cooled by the first wall to ~ 500 C and then removed from the chamber (through the laser ports) by the TM-DP's, for processing by the fuel recovery system (FRS). The pumps will be exposed to beta radiation from tritium, gamma radiation from the activation of Ar (Ar-41) and low levels of post detonation neutrons. Although the TM-DP's will be subjected to various radiations, current designs for similar pumping devices are hardened and have the ability of locating control electronics in remote (radiation) shielded enclosures. The radiation hardened TM-DP's will be required to operate with minimal maintenance for periods of up to 18 continuous months. As part of this initial investigation for developing a conceptual engineering strategy for a gas fill solution, commercial suppliers of low pressure (gas) pumping systems have been contacted and engaged in this study. Current technology is the area of mechanical pumping systems indicates that the development of a robust pumping system to meet the requirements of the FTF gas fill concept is within the limits of commercially-off-the-shelf (COTS) systems.

II. THE FUSION TEST FACILITY (FTF)



The Fusion Test Facility is a proposed next step in the development of a viable IFE direct drive power reactor for the generation of electrical energy. This progenitor device is designed to be a high repletion (5 Hz) ignition facility producing ~ 150 MW of fusion energy [3]. The FTF will be used to test various components and materials for future use in fusion power reactors. The production of 14 MeV neutrons generated by the FTF will produce a considerably high level of transmutations in various test components. Such experimental operations and testing are needed to develop the next generation of components and materials in both the IFE and MFE arenas. The FTF employs (modular) Krypton Fluoride (KrF) lasers as the driver for igniting direct drive targets. KrF excimer lasers with a fundamental wavelength at 248 nm in the ultra violent range, from a target physics perspective, have advantages for igniting direct drive targets. Another area of study in the FTF will be the effects of high energy (3.5 MeV) He ions on the surfaces of the first wall. With a currently proposed (spherical) target chamber radius of 5 meters, the FTF will have a chamber volume of 523,000 liters, and a surface area of 3,141,000 cm^2. The (shield) gas load in the target chamber vessel (Ar @1 torr STP equivalent) is calculated to be 523,000 torr-liters with a nominal mass of 5.25 µg /cc. Two parameters, excluding target injection heating and target positioning, which set limits of the gas fill concept is the mean free path (distance) to the target chamber wall, and the maximum gas load that can be used to attenuate He ions without hindering the ability of the KrF laser light to focus and illuminate the target. This is discussed later in the paper. Some advantages for gas fill may be gained with a different FTF target chamber configuration, which may make post detonation pumping (clearing out the chamber) more effective by achieving better system pumping. This is currently being investigated. For our initial study we consider relatively inexpensive Ar gas as a primary fill media. The following table depicts the stopping range of 3.5 MeV alpha particles in Ar gas [4].

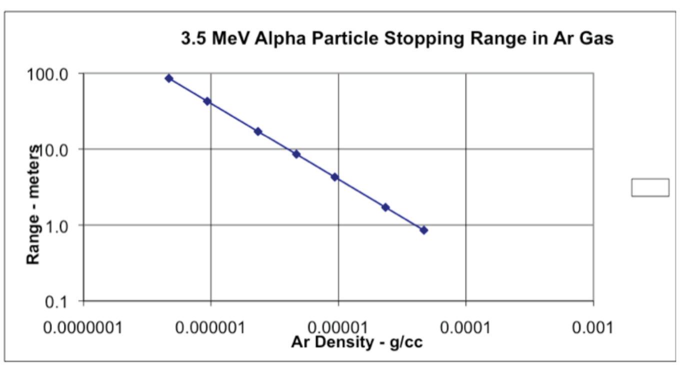


Figure 1. Stopping Range of Alpha Particles in Ar gas

III. KRF LASER INTERACTIONS IN AN AMBIENT GAS

During the 2003 time frame an experimental campaign was undertaken at Nike to evaluate the effects of an ambient, low pressure (up to 1 torr) noble gas, on the ability of the Nike lasers to focus in and illuminate a target. These experiments at NRL indicate that the use of a low pressure ambient gas, in the target chamber, show minor effects germane to focusing in on the target, but does not impede the ability of KrF laser light to illuminate the target. The observed effects and subsequent ability for the laser light to illuminate the target have also been confirmed by calculation (ref). As a result of these experimental results from Nike an ambient gas fill solution for extending the life of the first wall in the FTF is being further investigated.

IV. Scope of Conceptual Engineering Study

Currently we are investigating the first of three operating scenarios which include;

The evaluation of a low gas flow of approximately 1 - 5 M/sec in the target chamber is currently under investigation. In this operating mode the majority of the thermal load resident in the ambient (Ar) gas, resulting from post detonation heating, will be allowed to radiate out to the first wall. In this mode the first wall is engineered to have an active cooling system which maintains the gas fill media at a nominal temperature of ~ 500 C. The gas is then removed from the target chamber and directed to the FRS employing a radiation hardened mechanical pumping system designed for prolonged high temperature operations. The ambient gas, along with post detonation products are removed from the chamber and processed to reclaim un-expended fuel products, as well as remove non-useful components from the fuel cycle. The recovered shield gas in this mode is recycled back to the target chamber for additional service. Two additional operating configurations will also be investigated which include. These include an intermediate gas flow of approximately 10 M/sec. In this operating mode the thermal load in the gas will be removed by an external heat exchanger. The removed heat in this mode can also serve as a source of energy for additional use in the system. In this case the gas will be cooled, processed, and as in the previous operating mode, returned to the target chamber for additional service. In the final configuration to be investigated, the gas flow will be set at approximately 50 M/sec. In this mode the gas will be removed from the chamber, cooled, processed and as in the previous operating modes returned back to the chamber for additional service. In this configuration the possibility of establishing laminar flow will be investigated, by which target injection may be aided by the injected Ar gas stream. To make any of the above stated configurations work in an integrated FTF system, the mass flow of the entire system must be defined and balanced.

For the purpose of establishing an operational mass flow configuration, a model is being developed to evaluate components of the FTF fuel cycle. An earlier effort for the conceptual design of the FTF fuel recovery system is being revised to include the large increase in gas load due to the ambient fill gas. Additionally, new sub-systems for noble gas separation and revised fuel reprocessing parameters are being investigated. Effectively recycling process materials (fuel and fill gas) back into the FTF operations cycle is critical for operating the device in a efficient and economic fashion. The following chart identifies those components which are being defined in the mass balance model.

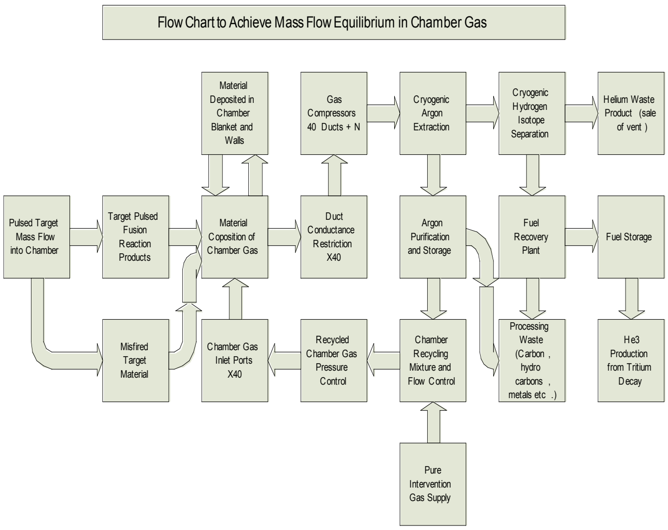


Figure 2. Mass Flow Chart of the FTF Gas Fill Process

V. Pumping System

As stated above a resident low pressure of approximately 1 torr (STP equivalent) noble gas fill in the FTF target chamber appears to be viable solution for attenuating helium ions from interacting with first wall components. A critical component to the success of this concept is the ability to effectively pump the chamber to remove components of plasma exhaust as well as the removal of heated and activated shield gas from the target chamber. Investigation of magnetically levitated, radiation hardened TMP/ drag pump hybrids with pumping speeds of 5,000 L/sec is being investigated with the commercial vacuum pumping industry. Interactions with industry representatives have been promising [5,6]. Two existing low-pressure gas pumping platforms, currently available, have been identified with some modification as being possible candidates for use in the FTF target chamber pumping system. Issues associated with processing radioactive and high temperature gases over prolonged periods of time have been addressed by the commercial sector in other applications, which have similarities with the requirements of the FTF vacuum pumping system. The ability to remotely located pump electronics in a shielded enclosure already exist as well as fabricating the pumps with metal seals.

VI. Conclusions & Path Forward

Use of a gas-fill in the FTF target chamber provides an elegant solution for extending the life of the first wall. A conceptual engineering study has been initiated to evaluate operational gas fill parameters and aspects of a mechanical pumping system required to employ a low pressure noble gas as a dynamic shield against post detonation helium ions in the FTF target chamber. The first gas being evaluated for this purpose is argon. Argon being a relatively inexpensive gas has good ion stopping properties. As part of this engineering study commercial suppliers of mechanical pumping systems have been contacted to assess the current state for high throughput low pressure pumping systems. The current state of the art for such pumps indicate that with some minor modification to current off the shelf components a mechanical pumping solution is within reach for the required purpose. Studies at Nike show that at pressures of 1 torr, a noble gas resident in the target chamber does not appear to impede the ability of KrF laser light from illuminating direct drive targets. Issues associated with heat build up on direct drive targets and positioning, when injected into a low-pressure noble gas environment need to be further analyzed. Increased gas load generated from the gas fill needs to be processed by the plasma exhaust fuel recovery system. Processing of this gas will require a scale up in size to the existing conceptual design for the FTF plasma exhaust processing system. This also is being evaluated. The strength of the gas fill concept is the relatively simplicity of this sub-system when compared to other proposed methods for extending the life of the first wall.

VII. References

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