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RAGS: The Gaseous Sample Collection Diagnostic at the National Ignition Facility

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ABSTRACT:

Radiochemical diagnostic techniques such as solid- and gas-phase capsule debris analysis may prove to be successful methods for establishing the success or failure of ignition experiments at the National Ignition Facility (NIF). Samples in the gas phase offer the most direct method of collection by simply pumping out the large target chamber following a NIF shot. The target capsules will be prepared with dopants which will produce radioactive noble gas isotopes upon activation with neutrons. We have designed and constructed the Radchem Apparatus for Gas Sampling (RAGS) in order to collect post-shot gaseous samples for NIF capsule diagnostics. The design of RAGS incorporates multiple stages intended to cryogenically purify, transfer, and count the radioactive decays from gaseous products synthesized in NIF experiments. An implementation timeline at NIF is discussed.

Index Terms – NIF, noble gas, xenon, diagnostic, RAGS.

I: INTRODUCTION AND BACKGROUND

The National Ignition Facility (NIF) is currently the world's most energetic laser system. Many scientific programs are interested in using NIF to study areas such as nuclear astrophysics, high energy density chemistry and physics, and stockpile stewardship, in addition to researching inertial confinement fusion (ICF). Greater than thirty diagnostic capabilities are in place or are planned for upcoming deployment on the NIF target chamber (TC) [1-3].

One of these diagnostics is the collection of gaseous activation products generated in a NIF laser shot and their subsequent analysis. Both neutron and charged particle reactions are expected to take place, probing different distance regimes in the target capsule [4]. Neutron-induced reactions will involve a larger distance over which these reactions can take place as compared to the proton, deuteron, or alpha-particle reactions. Simulations have shown that measuring ratios of noble gas products from neutron-induced reactions can give us a good measure of ρR, or fuel density, of the NIF capsule [5]. This technique can also cross-check other diagnostics, such as the neutron time-of-flight (nTOF) systems.

By doping the innermost layer of the target capsule's ablator shell with a known quantity of a desired detector nuclide, one can learn many things about what processes took place inside the capsule by measuring the number of neutron activations that occurred. A schematic of this is shown in Figure 1. The current plan is to use ^{124}Xe as the tracer, which will undergo (n,2n) and (n,γ) reactions, producing ^{123}Xe and ^{125}Xe ($t_{1/2}$ = 2.08 h and 16.9 h, respectively) [6]. 10^{15} atoms of Xe tracer will be doped in the capsule in order to create a large enough number of atoms for a post-shot measurement with reasonable statistics. Tracer amounts in excess of this

value could interfere with the capsule's performance. In the future, other tracers such as Kr, and possibly Ar will be used for similar reaction purposes.

Background interferences fall under three categories: environmental, residual, and shot-induced. Environmental background arises from elements present as part of the NIF structure, or those that are from the residual vacuum. Residual nuclides that pose a source of background are those that are left over from a previous shot. These residual interferences can be greatly reduced by flushing our gas system with pure gas/es to restore the normal isotope composition, or by waiting a given amount of time for the short-lived species to decay away. The largest source of shot-induced interference is anticipated to be fission products from the depleted uranium hohlraum in D-T ignition shots.

Collecting a representative sample of activation products is crucial, but challenges to this process exist. Capsule debris characterization and transport are not well understood in the real NIF environment. Chemical compound formation may segregate elements and produce a falsely low result. However, if noble gases emerge as neutral, monatomic species, they are expected to stream into the NIF pumping system, thereby avoiding collection of non-representative samples. Measuring ratios of the same element (e.g. $^{125}Xe/^{123}Xe$) removes issues in determining collection efficiency. To measure both neutron and charged-particle reactions simultaneously requires tracers to be loaded into the capsule along with the detector elements of interest.

A similar gas collection system was built and tested at the OMEGA laser at the Laboratory for Laser Energetics (LLE) in Rochester, New York [7]. The OMEGA Gas

Sampling System (OGSS) [8] performed well, collecting >75% of noble gases introduced to the system.

II: DESIGN AND THEORY OF USE

We have designed and begun to build a gas purification and collection device called RAGS, short for Radchem Apparatus for Gas Sampling. RAGS is constructed from commercially-available components from companies such as MDC, Swagelok, MKS, Pfeiffer, SRS, SAES, and Parker. Monitoring and operation of RAGS valves, pressures, and temperatures will be computer-controlled using proprietary LLNL codes. Appropriate gamma shielding for personnel safety will be in accordance with LLNL and NIF safety guidelines, and is currently under study.

When RAGS is in operation, all NIF TC effluent is routed through the RAGS system before it is exhausted. The average base pressure of the NIF TC under vacuum is on the order of 10^{-6} Torr. This vacuum is maintained by a roughing system, three turbo pumps, and four cryo pumps. In order for RAGS to achieve the maximum collection efficiency, the noble gas products must not be stream through the NIF cryo pumps, or else they will be collected prematurely and taken out of the effluent stream. This is achieved by isolating the NIF cryos a few seconds prior to a shot. This short time window also ensures that a minimal amount of ice forms on the cryogenic NIF target, which would adversely affect its performance.

The RAGS system consists of a few main sections: two gas puff units, a pre-cleaner, a cryo collection/fractionation system, and two gamma detection setups. These will each be covered in detail in the sections that follow, and a schematic can be seen in Figure 2.

A. Gas Puff Units – There are two gas puff systems planned for the RAGS system on NIF. The first is for calibration purposes, and will consist of a mixed source of stable noble gases such as Ar, Kr, and Xe released into the NIF TC. The amount of gases and the composition of the mixture will be well-characterized. The amount that is pumped through the TC and all subsequent piping will be collected through RAGS and measured by a noble gas mass spectrometer. This calibration puff procedure is planned to take place in the days preceding a few hours prior to a shot.

The second gas puff system is a He puff used to aid in transport of the products after a NIF shot. The large amount of undesired gases filtered out of the NIF TC effluent (see pre-cleaner section) means that the overall pressure will be reduced greatly in a short linear distance through the RAGS system, and could cause the product/s of interest to stagnate and not progress to the cryo collector stage. The He transport gas is desirable because it will neither react chemically with the pre-cleaner getters nor be cryogenically removed and "clog" the cryo heads. The exact location of where the He gas puff will be introduced in the RAGS system is still under discussion at this time.

B. Pre-cleaner System – The first part of RAGS that a gaseous effluent stream encounters is the pre-cleaner. Within the pre-cleaner there is a cryo head designed to freeze out water vapor but not entrap our noble gas products of interest, followed by a series of chemical getters. At present there are plans to include four getter stations, but the modular design of RAGS allows for a greater or lesser number if required. The first getter is unheated to remove hydrogenic molecules. The following getters are heated to 280 °C to remove CO_2, CO, N_2, O_2, etc., producing a stream of pure noble gas products.

C. Cryo Collection/Fractionation System – The purified noble gas stream from the pre-cleaner section then enters the cryogenic collection and fractionation system. First, the Xe is collected on a main cryo head while the remaining He and other gases pass by. After a few minutes, a valve between the pre-cleaner and the cryo-collector phases is closed, allowing no new gases into the cryo collector system. Depending on the yield of the individual shot, the sample will be held for one to several hours to allow for short-lived noble-gas fission product contaminants from the depleted uranium hohlraum to decay away.

At this time, the main head is warmed to release the gases it has collected, and these gases continue to a second cryo head designed to further purify the sample for *in-situ* gamma spectroscopy. The sample is later transferred to a small cooled sample bottle for removal and gamma counting at LLNL's low background nuclear counting facility.

D. Gamma Detection Systems – $LaBr_3(Ce)$ (or LaBr) and HPGe gamma detectors will be in use with RAGS [9,10]. The LaBr detectors will be located in four different sites on RAGS: the cryo cleaner, the final getter cartridge in the pre-cleaner, the main cryo collector head, and a cryo head used for cleanup downstream of RAGS. These LaBr detectors are process detectors used for real-time monitoring of the post-shot activity as it progresses through the system.

There are plans for a small array of HPGe gamma detectors at the secondary cryo head location of the cryo collector station for *in-situ* counting of collected samples. These detectors will be on linear slides operated remotely from the NIF control room to adjust the response of the detectors for the most efficient counting geometry.

III: CURRENT STATUS AND FUTURE PLANS

The first stage deployment of RAGS on NIF is planned for early calendar year 2011. This first stage will consist of both gas puff systems, the pre-cleaner, main cryo collector, and a cooled sample removal bottle.

Future improvements on the RAGS system will be implemented in stages. The second stage of RAGS involves the addition of the secondary cryo head and *in-situ* detection capabilities, to be delivered mid-calendar year 2011. Future stages such as parallel cryo collection and sample removal sections for Kr, etc. will be added on in series downstream of the Xe cryo station. These additional cryo collection sections will be added to the schedule based on the performance and results of the first two stages.

IV: CONCLUSIONS

We have designed and begun construction on the first phase of the RAGS noble gas collection diagnostic for NIF. Tracers will be added to NIF target capsules, undergo nuclear reactions, and be purified and collected for nuclear counting. Data obtained from this method will determine the ρR of the fuel, and also cross-check other nuclear diagnostic methods. Future RAGS capabilities include *in-situ* counting of gamma-emitting species, and the ability to purify and cryogenically separate Xe, Kr, and possibly Ar and Ne.

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CAPTIONS:

Figure 1 (color online): An illustration of the dopant activation and recovery planned for the Radchem Apparatus for Gas Sampling (RAGS) diagnostic. Left - Small circles represent NIF target capsule dopant atoms for use with RAGS. Center – Activation of the dopants during a NIF shot. Right – Collected activation products are counted to determine a ratio of products. Further interpretation of the ratio will yield information about the ρR in a given shot.

Figure 2 (color online): A schematic of the RAGS apparatus. Enclosures with dashed lines indicate multi-component systems mentioned in the main text for clarity. The dashed arrow leading from the He Gas Puff System indicates the exact introduction point is under study.

Figure 1

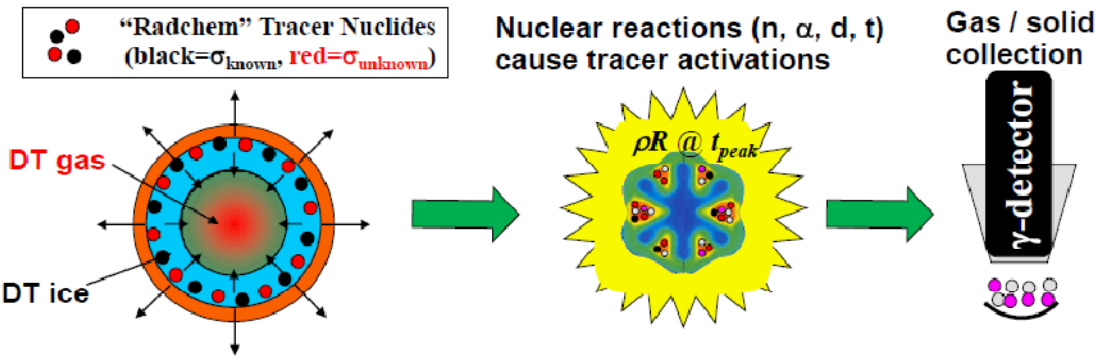
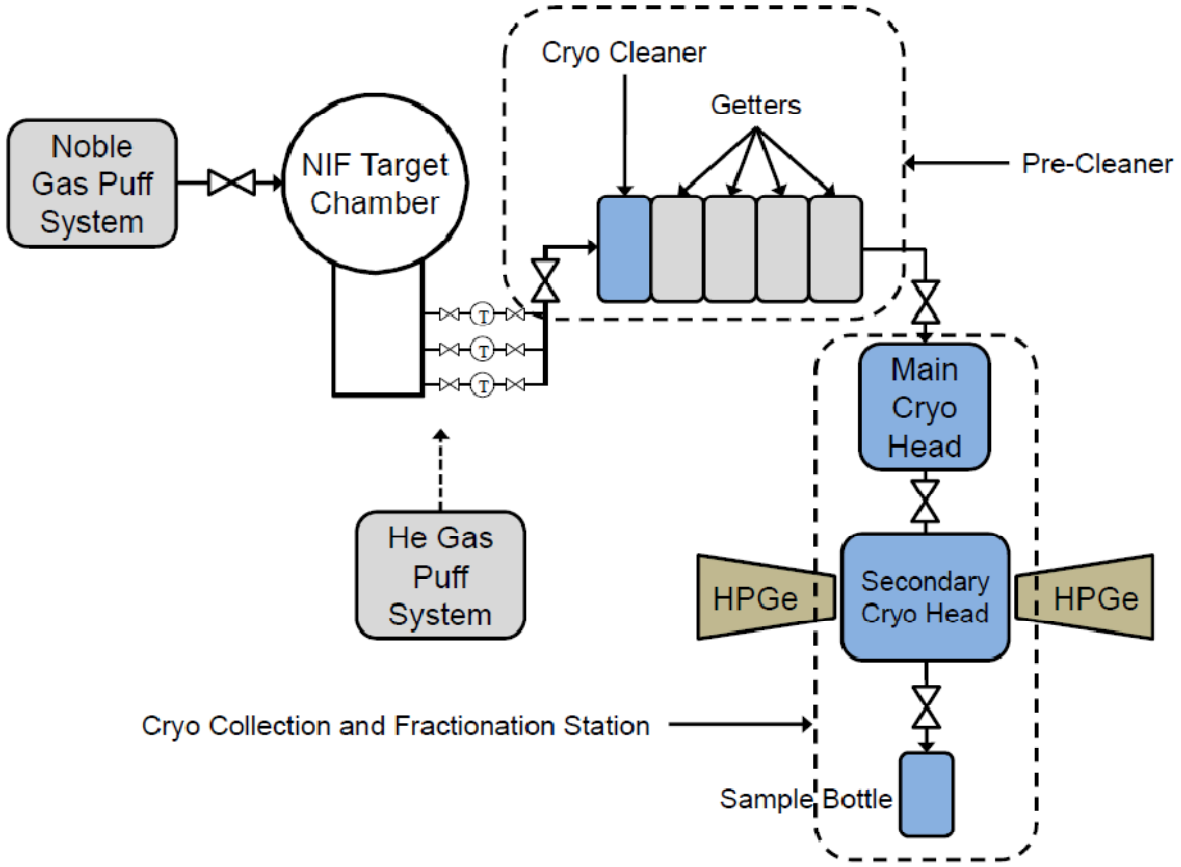


Figure 2


Cryo Cleaner
Getters
Pre-Cleaner
Noble Gas Puff System
NIF Target Chamber
Main Cryo Head
He Gas Puff System
HPGe
Secondary Cryo Head
HPGe
Cryo Collection and Fractionation Station
Sample Bottle