Noble Gas Analysis for the OMEGA Gas Sampling System

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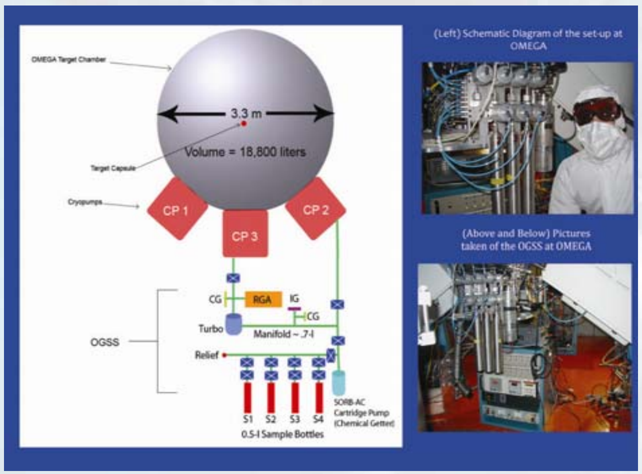
What is the OGSS?

The OGSS is a radiochemical diagnostic that can be used to study a wide variety of implosion parameters in inertial confinement fusion capsules. The OGSS was developed at Lawrence Livermore National Laboratory (LLNL) and is currently installed on the OMEGA target chamber at LLE. The OGSS is a prototype for a gas sampling diagnostic which may be installed at the National Ignition Facility (NIF), currently under construction at LLNL. By doping the target capsule with carefully chosen detector nuclei, nuclear reactions between fusion products and the detector nuclei can produce noble gas isotopes. Following a capsule implosion, these gases are pumped out of the OMEGA target chamber and are collected on a cryopump head. Upon regeneration of the cryopump, the OGSS turbopump pumps the gases into up to four 0.5 liter sample collection bottles. The composition of the sample collection bottles is analyzed using either mass spectroscopy or gamma ray spectroscopy, depending on the particular noble gas isotope formed in the reaction.

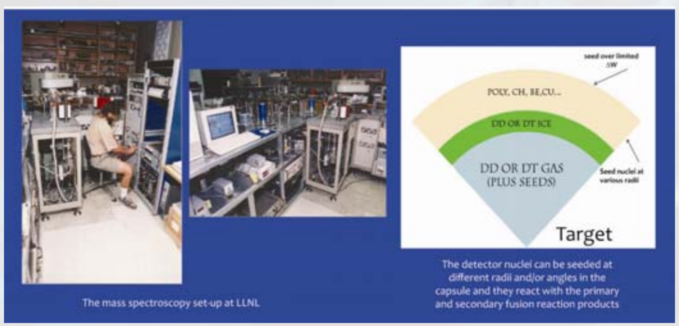


(Left) Schematic Diagram of the set-up at OMEGA

(Above and Below) Pictures taken of the OGSS at OMEGA

Why Gas Sampling?

The OGSS is a very versatile and efficient diagnostic. By suitable choice of reaction, the OGSS can be used to study fuel and shell areal densities, neutron yield, and mix. This diagnostic also has a very high efficiency compared to other diagnostics -- close to 100% of the reaction products can be collected in the sample bottles. The OGSS is non-intrusive and is relatively insensitive to EMP or x-rays. Also, choosing reactions which result in radioactive products makes detection easier and reduces background from other shots (if the half-life is sufficiently short, then background production nuclides from prior shots will have decayed away).



The mass spectroscopy set-up at LLNL

The detector nuclei can be seeded at different radii and/or angles in the capsule and they react with the primary and secondary fusion reaction products

How Does the OGSS Work?

Before a shot takes place, cryopump 3 (CP3) is isolated, regenerated, and allowed to cool back down. Approximately one minute before the shot, CP3 is opened to the chamber and CP1 and CP2 are closed. After the shot, CP3 is allowed to pump on the chamber for approximately two minutes. Since the pumping time constant is roughly 3-4 seconds, this is sufficient time to collect nearly 100% of the sample from the target chamber onto the cryopump head. CP1 and CP2 are then opened to the chamber and CP3 is closed. Roughly eight hours are necessary for CP3 to regenerate before the gases are transferred to the OGSS sample bottles.

The following day, the OGSS manifold and sample bottles are evacuated with CP2. The manifold is isolated from CP2 and the turbopump is used to transfer the gases from CP3 into the sample bottles. A residual gas analyzer (RGA) gives a rough measurement of the abundances of gases in "real time" as they come off the cryopump head. A chemical getter pump, used to back the turbopump, removes tritium and other contaminants from the sample but allows noble gases to pass into the sample bottles.

OGSS Efficiency Measurement: Preliminary Results

Initial results for first OMEGA gas cocktail recovery experiment

Estimated absolute recovery (based on estimated fill)

	Sample Bottle 1	Sample Bottle 2	Sample Bottle 3	Average	Rel. Std. Dev.
22Ne	77%	83%	91%	84%	8%
80Kr	72%	72%	79%	74%	5%
86Kr	74%	73%	80%	76%	5%
134Xe	105%	106%	110%	107%	2%

Bottle gases are likely identical, variations due to measurement uncertainty

Background Results

	Equivalent Amounts of Air (cm^3 STP)			Average	Rel. Std. Dev.
He	987	1083	1035	1035	5%
Ne	6.5	5.9	7.1	6.5	9%
Ar	233	253	222	236	7%
Kr	0.26	0.26	0.30	0.27	8%
Xe	0.23	0.20	0.24	0.22	9%

Suggests non-atmospheric sources for He and Ar, total ^{3}He was 1.0×10^{15} atoms

Sample	Number of Sample Atoms	Number of Background Atoms	Sample-to-Background Ratio
^{22}Ne	9.6×10^{14}	2.9×10^{14}	3.3
^{80}Kr	1.2×10^{14}	1.9×10^{11}	640
^{86}Kr	1.2×10^{14}	1.4×10^{12}	86
^{134}Xe	1.7×10^{14}	5.4×10^{12}	3200

- 879µm OD CH capsule with 19.5µm shell wall thickness
- Capsule filled with 0.92 atm noble gas cocktail consisting of isotopes 22Ne, 80Kr, 86Kr, 134Xe (7:1:1:1 ratio)
- Shot with 6 beams full of energy on 3/11/2004

Some Sample Reactions to Show the Potential of the Technique

$^{18}O(\alpha,n)^{21}Ne$

A potential mix reaction using limited α range

Low Background

The final product is counted using mass spectroscopy

$^{38}Ar(n,2n)^{37}Ar$

A potential neutron yield and fuel ρR reaction – neutrons sample Ar in core

No background and long half-life (35 days) – ^{37}Ar counted using γ spectroscopy

$^{79}Br(d,2n)^{79}Kr$ and $^{79}Br(p,n)^{79}Kr$

A potential probe of shell ρR using primary and knock-on fusion products with significantly longer ranges

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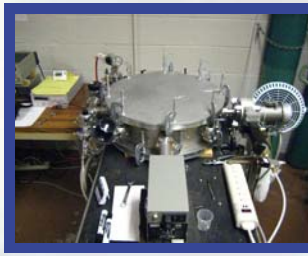
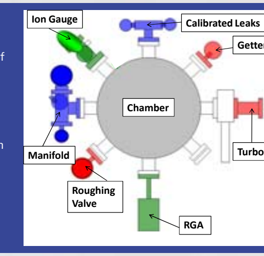


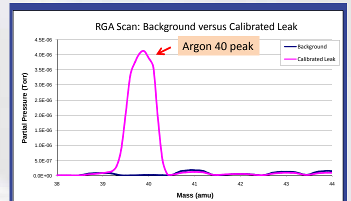


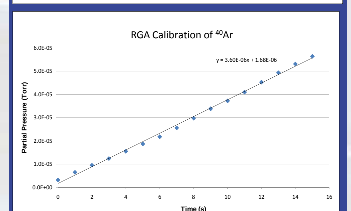
Left: A picture of the vacuum chamber fitted with various hardware

Right: A diagram of all the connections to the vacuum chamber

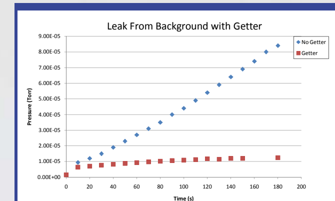
Current Research

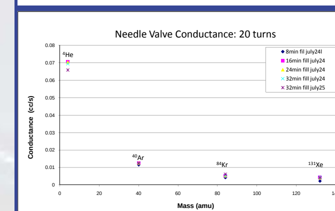
Currently at SUNY Geneseo, research is being done to develop a process by which the contents of the gas in the OGSS sample bottles can be determined. The gases from the sample bottles are admitted into a vacuum chamber and the contents are analyzed using a residual gas analyzer (RGA). The RGA allows the partial pressures of each type of gas in the chamber to be measured, however the response of the RGA needs to be calibrated before it can be used for quantitative measurements. RGA calibrations are performed using a set of calibrated leaks mounted on the chamber. Since the leak rates from the calibrated leaks are known, the response of the RGA for each type of gas in the calibrated leak can be determined. Due to the relatively high pressure of the sample bottles (~1 torr), a manifold was added to isolate the sample gas from the chamber. This manifold is fitted with a low conductance needle valve with an adjustable leak rate which allows gas from the OGSS sample bottles to flow into the chamber at a controlled rate. This allows the pressure in the chamber to be kept below 10^{-4} torr, which is the upper limit for the operation of the RGA. Background from non-noble gasses is removed from the chamber using a chemical getter pump. The chemical getter only pumps out non-noble gases and does not pump out the noble gas atoms that constitute the signal from the OGSS.





Top: Partial pressure as a function of mass number. RGA response for gas admitted into chamber from calibrated leak is compared with RGA response for chamber background in this mass range.
Bottom: Partial pressure of 40Ar as a function of time with calibrated leak open. Plots like this are used to calibrate the response of the RGA for the different gas species.





Top: Total chamber pressure as a function of time. The data compares the case with the getter closed off from the chamber with the case with the getter opened to the chamber. Notice that the getter is effective in keeping the total chamber pressure below the RGA operating limit (1×10^{-4} torr) for over one hour.
Bottom: Conductance through the needle valve for various types of noble gases (Helium, Argon, Krypton, and Xenon).

Future Goals

More studies of the conductance of the needle valve as a function of gas type, manifold pressure, and number of turns on the needle valve need to be performed. In addition, the conductance of the needle valve needs to be studied under conditions in which a mixture of gases are present in the manifold. Finally, once our analysis technique is finalized, we will analyze the contents of an OGSS sample collection at OMEGA in a D-3He capsule implosion. The goal of this measurement will be to measure the OGSS collection efficiency.