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Construction, Startup and Initial Operation of Ignition Fusion Target Tritium Fill Systems at LLNL

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A specialized tritium handling capability has been constructed in Building 331 at LLNL (the LLNL Tritium Facility) to assist with the preparation of targets for the National Ignition Facility (NIF). This capability is provided primarily through the operation of three major new work stations, the Tritium Science Station (TSS), the Tritium Processing Station (TPS) and a High Resolution Mass Spectrometer. This paper briefly describes the design philosophy, current operations and issues and possible upgrades for each.

I. INTRODUCTION

It has long been recognized that an ignition capable Inertial Confinement Fusion (ICF) device such as the NIF would require a supporting local tritium handling capability. The Tritium Facility Modernization (TFM) project was designed to meet that need by expanding and modernizing exiting capability at the LLNL Tritium Facility along with the addition of new systems where warranted. Recent activation of the Tritium Processing Station (TPS) completes implementation of TFM and positions the tritium facility to fully accommodate NIF tritium target support requirements.

The present work summarizes major operational capabilities ("workstations") now active at the tritium facility in the context of present and projected NIF tritium support requirements. Three workstations, a high resolution mass spectrometer, the Tritium Science Station (TSS), and the Tritium Processing Station (TPS) are described.

II. TRITIUM SCIENCE STATION

The TSS is a versatile, general purpose work station providing basic tritium handling services for a variety of experiments in addition to NIF support. It has been in operation with tritium since October 2008.

II.A Design and Functional Description

The TSS, pictured in Figure 1, relies on a familiar set of proven tritium handling technologies for most of its functions.

Fig. 1. TSS front view.

Referring to a Figure 2's simplified flow schematic, chemical purification and long term storage are provided by three uranium beds (U-beds). Two of these beds are each paired with a Pd bed (i.e. "Pure" and "Mixed" U and Pd bed pairs). The third or "Scrap" U-bed collects used tritium and tritium mixes for later shipment to Savannah River for recycling.

The two Pd beds are used to generate pressure and also to remove ^{3}He. After a bed is charged with tritium from one of the storage U-beds it is chilled to ~ -80^{o}C. At this temperature the partial pressure of tritium over Pd is very low, allowing residual over gas ^{3}He to be pumped away. Taking advantage of Pd's unique retention properties for internally generated ^{3}He, the bed may then be heated to produce a very nearly ^{3}He-free product gas.

The production of precisely known, highly uniform tri-isotope mixes (e.g., 72:22:6 T:H:D) is a major NIF requirement supported by TSS. It is achieved in TSS through use of a “mix manifold” consisting of well characterized and conditioned mix vessels attached to a common manifold section. Designated vessels are filled with the correct amount of pure isotope by PVT and then allowed to diffusively mix. From diffusion modeling, confirmed by experiment, a minimum of 41 hours is required to assure complete mixing.

bottle regulators are being retrofitted from the current maximum of ~ 115 psia to permit this upgrade.

Another strategy shift has seen all fills to date use the PVT/diffusive mix strategy as opposed to direct filling from a pre-mixed bed. This approach, while more accurate and flexible, does delay availability of the fill gas

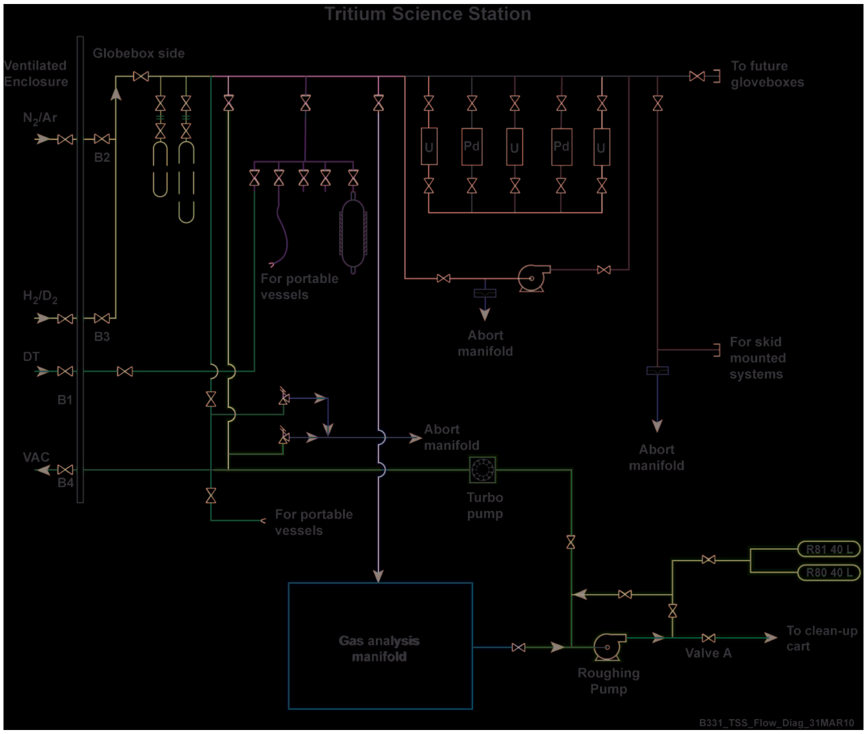

Fig. 2. TSS flow schematic.

II.B Current Operations

The TSS is currently hosting three diverse experiments, one exploring tritium effects on polymers, another concerned with tritium and ^{3}He behavior in Pd and a third attempting to understand the extent and source(s) of methane build up in NIF target gas mixes.

These experiments are in addition to the baseline TSS function of providing tritium target fills for the NIF.

II.C Issues and Upgrades

As NIF target designs and fill strategies have evolved (and continue to evolve), the TSS has been reconfigured to compensate. In the most recent shift target gases are now mixed and delivered via a “remote reservoir” as opposed to the prior practice of close coupling the target and fill gas reservoir. To compensate for the longer line volumes higher fill pressures, up to 150 psia, are now required. Higher range pressure transducers and lecture

and add to its ^{3}He “age” (hours since removal) by at least 41 hours. Fortunately the non-ignition THD shots are not sensitive to ^{3}He and reservoirs are usable for a week or more, assuming methane buildup is not excessive. The diffusive mix/ higher pressure strategy uses significantly more tritium in the form of discarded mix gases.

The higher fill pressure requirement coupled with the diffusive mix strategy choice has also led to a decision to operate both Pd beds as pure tritium source beds. A logical future upgrade would be the addition of more and larger capacity bed pairs, one or more of which could be devoted to the direct fill of commonly requested THD recipes.

Backstreaming of discarded light isotopes from the vacuum system dump tanks is occasionally an issue, especially when using the on-board RGA. Addition of a second turbo pump in series with the current one is one possible solution.

III. TRITIUM PROCESSING STATION

The TPS, pictured in Figure 3, is the latest addition to the LLNL Tritium Facility's upgraded capabilities, receiving final approval for radiological operations October 4, 2010. Its primary function is the supply of NIF ignition target mixes, nominally 50:50 D:T, and any other recipe involving only these two heavy hydrogen isotopes (e.g. 98:2 T:D) and possibly chemically inert gases such as ^{3}He. Protium is aggressively minimized throughout TPS.

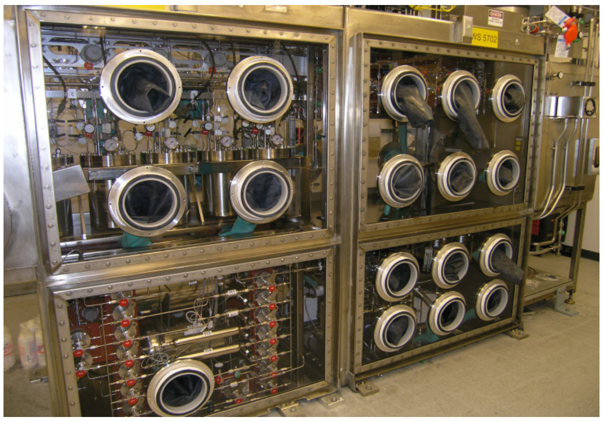

Fig. 3. TPS front view.

III.A Design and Functional Description

TPS design takes full advantage of the template established by the TSS. As for TSS, tritium and standard mixes of deuterium/tritium are stored on uranium beds for chemical purification and delivered from palladium beds, which act to remove ^{3}He and generate pressure.

A notable TPS upgrade is the addition of a Johnson Matthey Pd-Ag Diffuser (See Fig. 4). Use of the diffuser will enable total removal of ^{3}He very late in the target gas delivery sequence, thus resetting the ^{3}He age clock to zero up to 3 hours closer to shot time. As ^{3}He acts as nuclear fusion "poison", minimizing its presence is important.

Storage bed design has also changed significantly from TSS to TPS. Driven by an original TFM project requirement to support high pressure (permeation) target fills, TPS beds are much larger than those used in TSS, for example, TPS U-beds have a 120 standard L hydrogen capacity vs. 1720 sml for TSS. Due to their large thermal inertia and high tritium capacity, all TPS beds are secondarily contained and its U-beds are actively cooled.

III.B Current/Future Operations

TPS is in the early stages of its Startup Plan, exercising all major functions with a low tritium, "spiked" deuterium source. It is on schedule to have demonstrated delivery of a 50:50 D:T ignition target fuel mix fully meeting NIF specifications by February 2011.

Unlike the PVT/diffusive mix strategy employed for THD targets in TSS, it is expected that NIF ignition fill gas will come directly from a pre-mixed D-T bed, appropriately biased rich in D to yield the canonical 50:50 D:T mix.

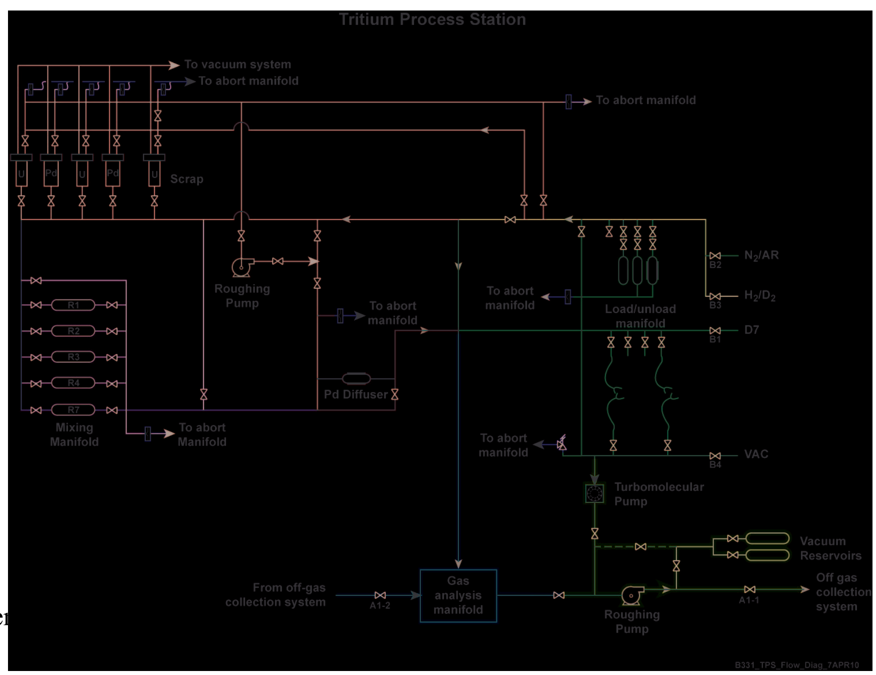

Fig. 4. TPS flow scher

III.C Issues and Upgrades

The inevitable buildup of protium in TPS's tritium storage beds is of concern. Thorough, repeated conditioning with deuterium and secondarily with tritium for the pure tritium beds is the principle approach being used to minimize this problem.

The large bed sizes in TPS also help with the protium buildup issue by diluting the effect of incoming environmental protium. However, unnecessarily large beds are slow to operate and tie up considerably more tritium inventory than currently necessary for NIF support. A future upgrade could replace these beds with scaled down versions.

IV. HIGH RESOLUTION MASS SPECTROMETER

Accurate isotopic and chemical analysis is critical both to produce and later confirm target fill gas mixes that meet NIF specifications. A newly constructed Finnegan's (Thermo Fisher Scientific) MAT-271 Mass Spectrometer, equipped with modern electronics and improved through selective automation of routine, repetitive tasks, provides these analyses at the LLNL tritium facility.

IV.A Design Description

Fig. 5 provides a front view of the facility's MAT-271. The temperature controlled inlet system is in the center of this photograph, just to the left of lead operator Jorge Sanchez. The mass spectrometer proper is to Jorge's right

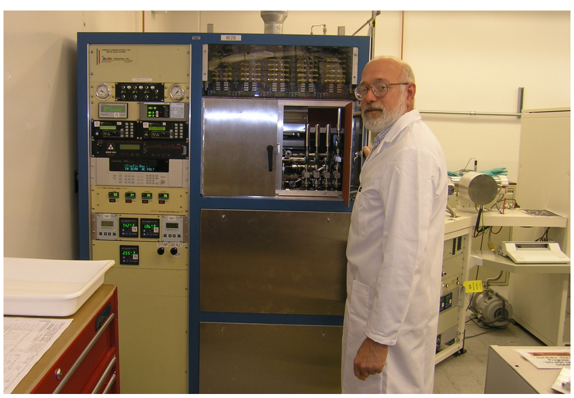

Fig. 5. Semi-automated batch inlet system.

Customized, PC-based control and analytical software integrates and automates many gas handling and mass spectrometer analytical functions, in particular, batch inlet system control with spectrometer control and data acquisition. User friendly process screens facilitate operator interaction.

IV.B Operational Characteristics

IV.B.1. Resolution limits

Faraday Cups: 600, 1400, 3400 (Δm/m)
Electron Multiplier: 1400 (Δm/m)

IV.B.2.Mass Scale Calibration

The following gas species are used for calibration standards: H_2, ^{3}He, He, DT, T_2, Ne++, Ne, ^{84}Kr++, and ^{84}Kr.

IV.C Analysis Results

Fig. 6 shows a typical analysis report from a recent NIF target fill.

IV.D Research Activities

While methanes show as non-detectable in the analysis presented in Fig. 6, their slow build up in high tritium samples is frequently observed and could become a limiting factor in the "shelf life" of NIF target reservoirs. Experiments are underway to quantify and, if necessary, mitigate this phenomenon in target reservoirs and their witness samples.

In addition to supporting NIF, the MAT-271 has and is contributing to Sandia tritium-in-metals and GE-Hitachi Nuclear membrane exposure experiments.

Date	09/23/10			Calibration Standards	20% Mix (Ar, CO_2, D_2, He, CH_4); HDT-TCV-32					Current Total atom% D Safety Basis Upper Limit*
Analyst	Chiarappa-Zucca			Cal Date	9/23/2010 (20% Mix); 9/23/2010 (HDT)					6.6
Witness S/N	MS 092310			Cal/Bkgd File	574438053_mix-20.sF4/574435287_SV-V39-42-4140.bF4					
Sample Bkg File	574455173_SV-39-42.bF4			Sample Sens File	SensFileSet_574447143.svs					
Gas Components*	Replicate A1 mole %	Replicate A2 mole %	Replicate A3 mole %	Average mole %	STDEV	% RSD	95% CL	Lower 95% CL	Upper 95% CL	
H_2	6.01	5.92	5.95	5.96	0.05	0.77	0.05	5.91	6.01	
^{3}He	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	
HD	2.47	2.49	2.48	2.48	0.01	0.40	0.01	2.47	2.49	
HT	29.39	29.26	29.32	29.32	0.07	0.22	0.07	29.25	29.40	
D_2	0.37	0.37	0.37	0.37	0.00	0.00	0.00	0.37	0.37	
DT	8.11	8.17	8.12	8.13	0.03	0.40	0.04	8.10	8.17	
T_2	53.66	53.79	53.77	53.74	0.07	0.13	0.08	53.66	53.82	
Methane*	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Ammonia*	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Water*	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Total Atomic Components	Replicate A1 Atom %	Replicate A2 Atom %	Replicate A3 Atom %	Average Atom %	STDEV	% RSD	95% CL	Lower 95% CL	Upper 95% CL	Witness Sample Total D Upper CL is within SB Limit (YES/NO)
H	21.94	21.79	21.85	21.86	0.08	0.35	0.09	21.77	21.95	
D	5.65	5.70	5.66	5.67	0.03	0.47	0.03	5.64	5.70	YES
T	72.41	72.51	72.49	72.47	0.05	0.07	0.06	72.41	72.53	

RSD=Relative Standard Deviation (SD/Average x 100)
CL= Confidence Limit

ND = Not Detected

* Max Credible Yield Memo NIF-5031646

Fig. 6. Target gas analysis.

ACKNOWLEDGMENTS

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