DOE Office of Science (SC)
Fusion Energy Sciences (FES)
Fusion Nuclear Science and Technology Program
Status and plans for tritium research

Presented by:
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34^{th} Tritium Focus Group (TFG) meeting
INL, Idaho Falls, ID
09/23-25/2014

Research Interest

The research interest in tritium science in the Office of Fusion Energy Sciences (FES) is in its use as the primary fuel for a self-heated burning plasma; to understand and manage the associated safety and processing issues; and to develop efficient breeder materials, models of tritium's affect on material properties, permeation windows, and permeation barriers, exhaust purification systems, tritium isotope separation systems, detritiation systems, tritium accountancy tools and models to support safety assessments.

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Presentation Outline

Background

Current research activities:

- Status and progress of the SBIR-funded nano-engineered solid tritium breeder fuel by a small business in California. $150K (FY12)+ $1M (FY13-FY14)

Newly funded tritium research activities:

- New LANL hydrogen processing loop experimental equipment completed in early FY15 under ITER IO primary and DOE/FES secondary funding. (FY15+)
- TSTA data mining activities planned at LANL with INL collaboration (FY15+)

Potential future research & collaborations

- New SBIR solicitation coming out soon for FY15
- Potential JET collaborations for D-T operations 2017 (neutronic, tritium, safety)
- DOE a potential T supplier to JET for their D-T operations.
- SUF in-pile testing of newly developed tritium breeding fuels from US small business, EU, KO through the ATR or HFIR user facility.
- Potential areas of common interest between BES, NNSA, NE and FES on tritium nano-materials, breeding fuels and liquid metal coolants.

LANL presentation: Hydrogen Processing Lab (HPL) collaboration between IO and FES

INL presentation: STAR tritium air monitoring upgrade plan

Seeking collaboration from TFG on areas of common interest in tritium research

- **Backup Slides: Fusion tritium challenge/questions to be answered**

Background

ITER will address tritium breeding, processing, safety and management issues

- ITER is designed to generate the world's first sustained (300 seconds, self-heated) burning plasma. It aims to generate fusion power 30 times the levels produced to date and to exceed the external power applied to the plasma by at least a factor of ten.
- ITER will be a powerful tool for discovery, capable of addressing the new challenges of the burning plasma frontier and assessing the scientific and technical feasibility of fusion energy.
- ITER is going through a licensing process similar to other nuclear facilities of the host country (France).
- ITER will have the capability to test prototypic blankets for future facilities. There are 3 ports, each of which can test 2 blanket concepts at the same time.
- ITER will have the capability to process the unburned fuel (i.e. deuterium, tritium) in the plasma exhaust as well as the tritium generated in the test blankets modules.
- While ITER will provide a strong scientific basis for next step facilities, the US believes that there will still be a gap in the area of fusion nuclear science.
- To address this gap, the Fusion Energy Sciences program believes a Fusion Nuclear Science Facility (FNSF) is required.

Background

Fusion tritium state of the art vs. ITER vs. DEMO

Parameter	State-of-the-art	Need for ITER	Need for DEMO
Flowrate	6 liters/min	120 liters/min	120 liters/min
Recycle requirement	24 hr	1 hr	1 hr
Tritium inventory	100 gm	4000 gm	6000 gm
Duty Cycle	10%	5%	50%
Gaseous tritium release requirement	<0.02 g/y	<1 g/y	< ? g/y
Fusion power	None	400 MW	2000 MW
Tritium breeding requirement	None	None (1.4 kg tritium burned per year)	Must breed all tritium
Containment	The same worker, public, and environment limits		

	ITER	FNSF	Power Plant, 1000 MW_e
Neutron exposure life of plant $MW\text{-}yr/m^2$, dpa	0.3, 3.0	8.5, 85	60-98, 600-980
Materials	316SS, CuCrZr, Be, W, H_2O, SS304, SS430	RAFM, PbLi, He, SiC-c, Borated-RAFM, W, bainitic steel	RAFM, PbLi, He, SiC-c, Borated-RAFM, W, bainitic steel
Operating temperature, ^oC	100-150	400-600	600-700
Tritium breeding ratio	~ 0.003	~ 1.0	1.05
Plasma on-time in a year, %	5	~10-35	85
Plasma pulse duration, s	500-3000	~10^6 (2 weeks)	2.7×10^7 (10.5 months)

From FNS-PA report

FNSF fuel handling flow diagrams

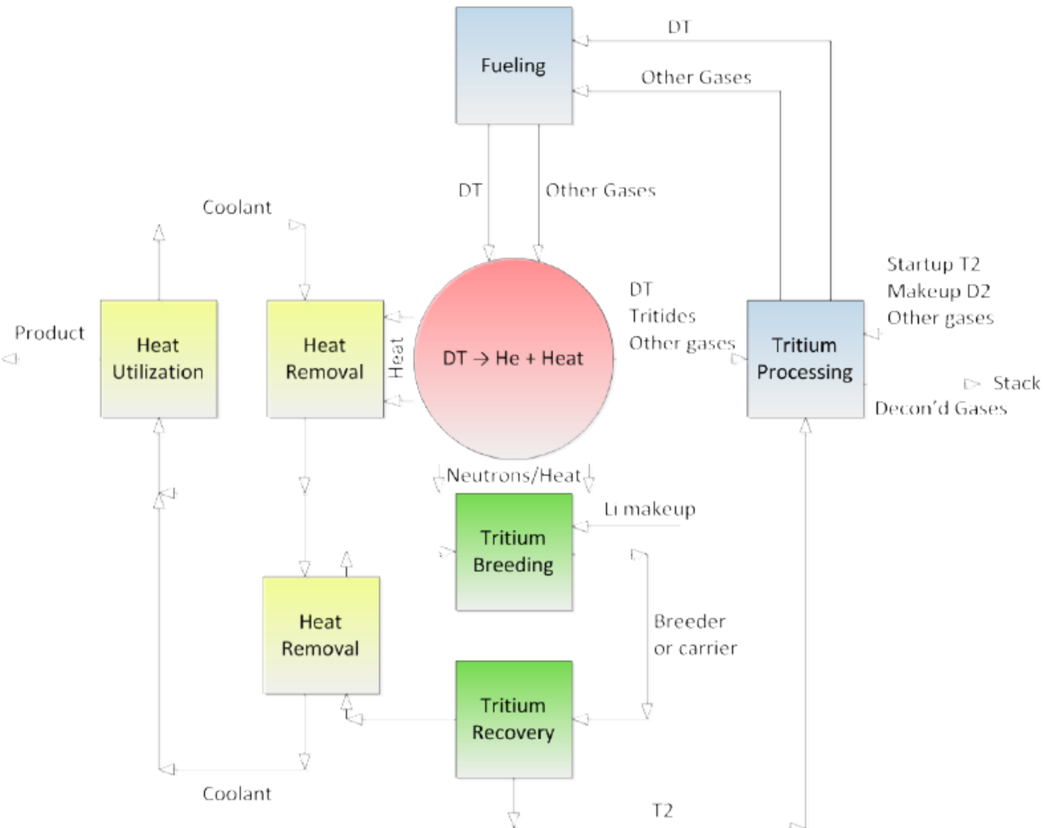

Fig. 3. Primary fusion fuel handling systems and interfaces

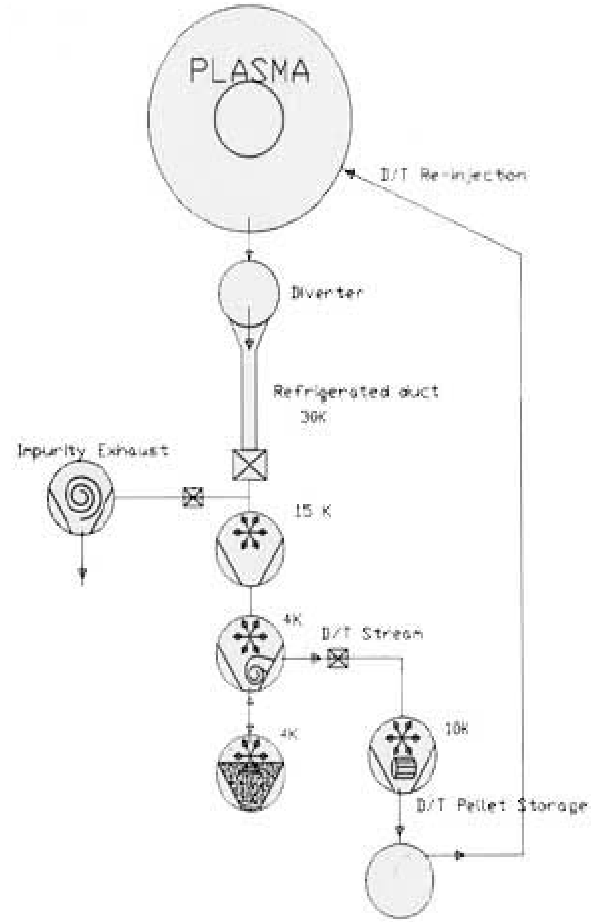

Fig. 2 Pumping scheme flow diagram for a FNSF that includes a continuous cryogenic diffusion pump and sorption pump for helium pumping.

From FNS-PA report

Background

FNSF fuel handling flow diagrams continued

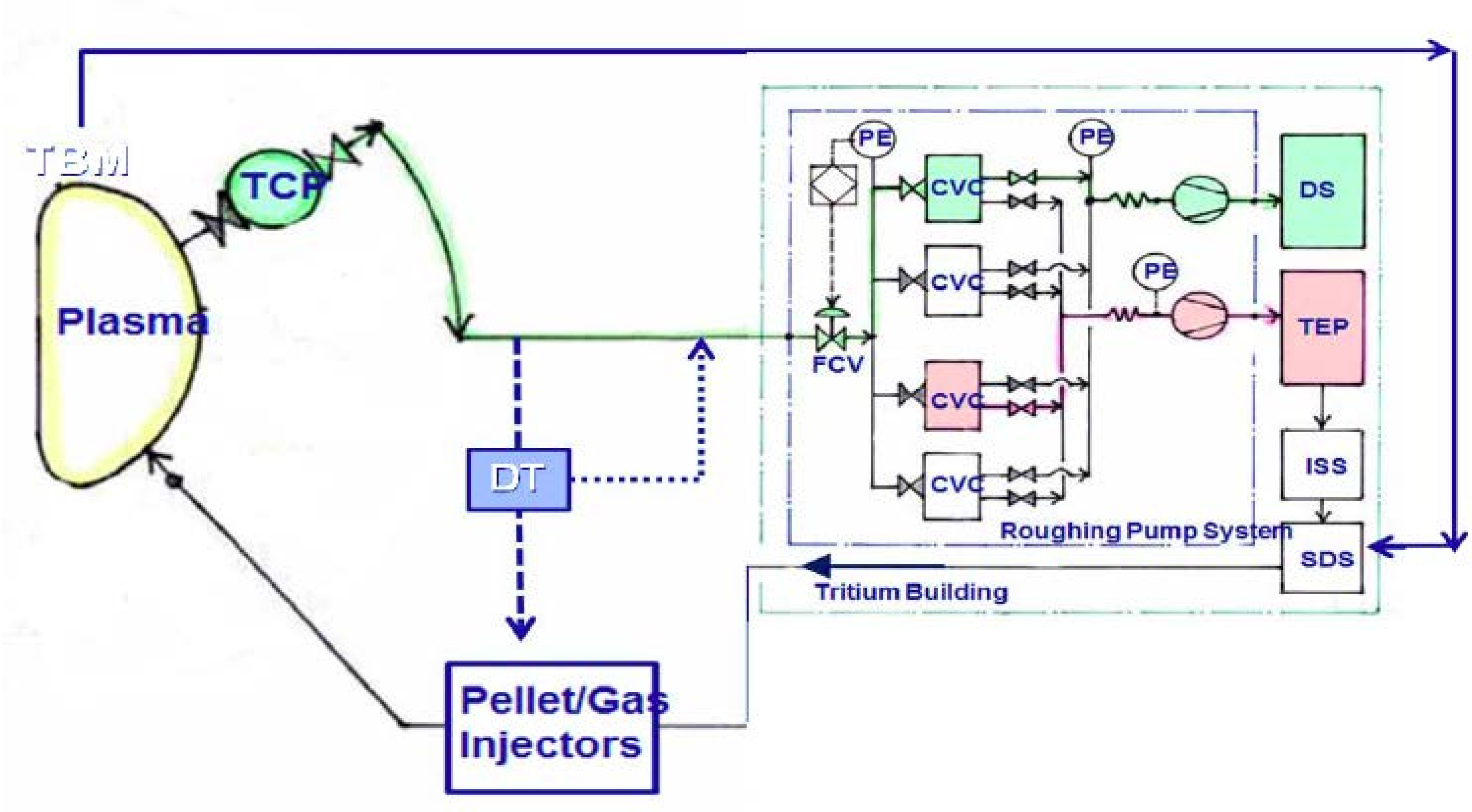

Fig. 1. Simplified fuel cycle block diagram for a FNSF.

From FNS-PA report

FES Research

1. Current research activities

- PHENIX collaboration with the Japanese
- Collaboration with Korea, supporting their ITER TBS CDR and safety analysis.
- Collaboration with India, supporting their ITER TBS CDR and safety analysis.
- Recently completed phase II SBIR-funded nano-engineered solid tritium breeder fuel by a small business in California. $150K (FY12)+ $1M (FY13-FY14).
  - Potential to continue research under base program funding
- New LANL/IO/FES collaboration on HPL upgrade (detailed slides to follow).
- INL TPE upgrades for increased power, control, safety nearing completion (seen on tour).
- INL STAR activities discussed yesterday, and seen on the tour: TPE, THX, TGAP, TLLE, code support for MELCOR, TMAP, etc.

FES Research

Newly funded tritium research activities:

- **New LANL hydrogen processing loop experimental equipment to be completed in early FY15 under ITER IO primary and DOE/FES secondary funding. (FY14)**
- **TSTA data mining activities to find data needed to support ITER tritium plant design decisions and support safety analysis documentation required for nuclear licensing. Activities planned at LANL with INL collaboration (FY15+)**
- **TSTA data transferred from paper to digital media, hosted on a searchable web site (FY15+)**
- **Upgraded capabilities at the TPE experiment for higher power, improved plasma control, improved worker safety (FY13-FY15).**

Potential future research & collaborations

- New SBIR solicitation coming out soon for FY15
  - Focus areas will be similar to past solicitations for breeder materials, tritium technology, and simulation tools. See http://science.energy.gov/sbir/
- Potential JET collaborations for D-T operations 2017 (neutronics, tritium, safety)
- DOE is a potential T supplier to JET for their D-T operations.
- Scientific User Facility (SUF) in-pile testing at the HFIR or ATR user facilities. Purpose of testing is tritium retention and extraction, breeding performance, and structural integrity under intense irradiation of the newly developed tritium breeding fuels from US small business, compared to existing solid and liquid breeder materials from the US, EU, KO .
- Potential areas of common interest between NE and FES on and liquid metal coolants.
- Potential areas of common interest between NNSA and FES on tritium breeding fuels.
- Potential areas of common interest between BES and FES on advanced materials and technologies such as engineered nano-structured lithium ion battery materials with a dual use as a lithium-rich breeder.
- Seeking collaboration from TFG on areas of common interest in tritium research.
  - One potential mode of collaboration is through a multi-lab Scientific Focus Area (SFA). BER is an example: http://science.energy.gov/~/media/ber/pdf/LaboratoryGuidance/Managing_BER_Scientific_Focus_Area_SFA_Programs_DOE_National_Lab.pdf

LANL HPL Capability

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UNCLASSIFIED

Hydrogen Processing Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

- Configuration flexibility
  - Multiple Gases (H_2/CO/CH_4/Inerts)
  - Ability to test Catalyst Reactor, Permeator (Diffusor), Palladium Membrane Reactor(PMR), Molecular Sieve Bed
  - Pressure/Temperature/Flow Control
  - Compositional analysis
    - Gas Chromatography
    - Humidity (trace/high dew point)
    - Mass Spectrometry (low mass, H/D)
  - Scalability of furnace/heating
- Uranium (Hydride) Bed
- Dedicated facility for energy research and separate from the LANL Weapons Engineering Tritium Facility (WETF)

Hydrogen Processing Laboratory

Figure 1: Overview of lab, with DAQ, Furnace, etc.

Figure 2: Detailed view of the HPL bench from right side.

Significant Contributions to Fusion Science

- R&D for Design of Tokamak Exhaust Processing (TEP) System, ITER
  - Catalyst Testing
    Validation of catalyst model with experimental data
  - Permeator/PMR
  - Molecular Sieve Beds

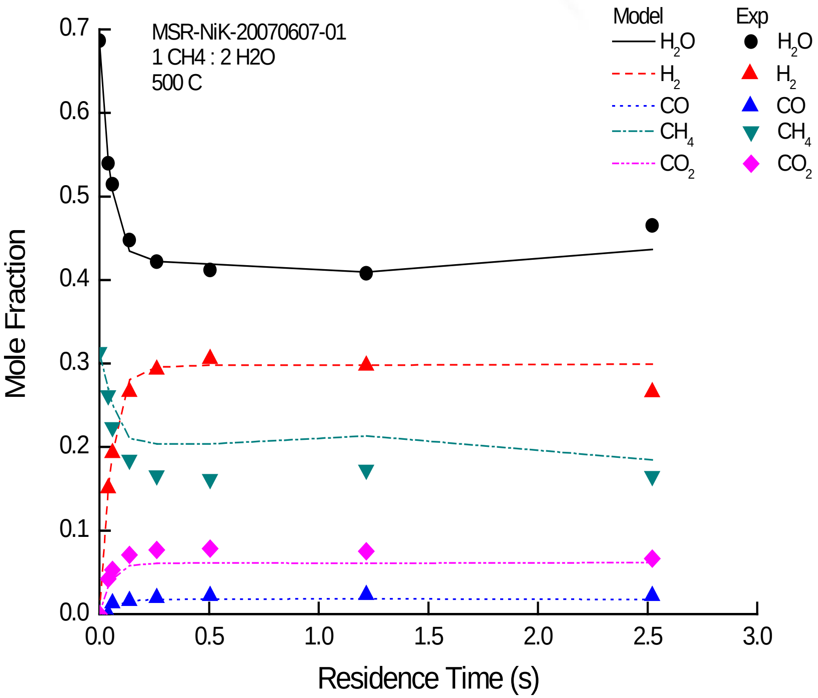


Figure 3: Example of experimental data

Conceptual Design for TEP System, ITER

- Integration of HPL experimental data with TEP modeling / sizing

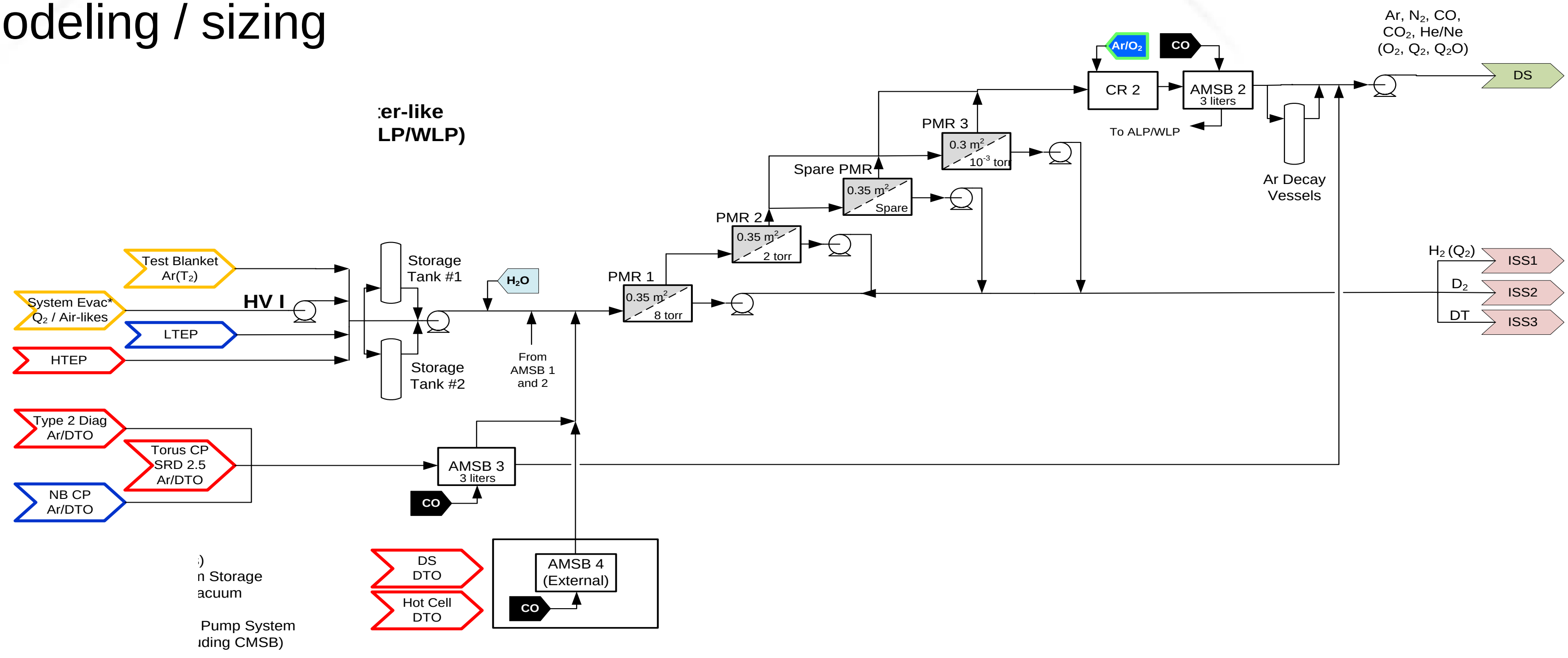
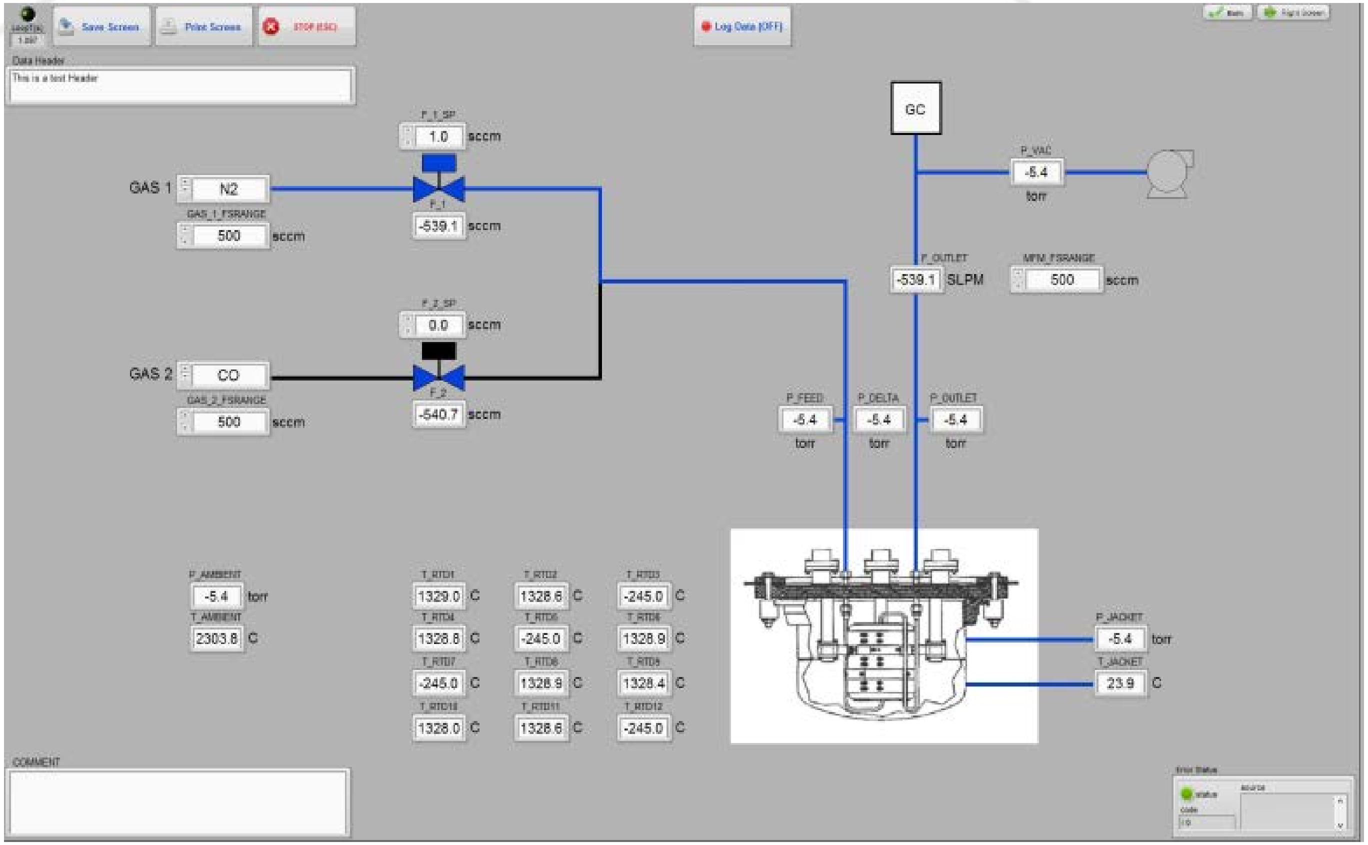


Figure 4: ITER TEP system conceptual process flow diagram for processing.

HPL Hardware/Software Upgrades

- Data control/acquisition
  - 16 channel Thermocouple
  - 12 channel RTD (Thermal)
  - 16 channel Analog Input
  - 32 channel Analog Output
  - Expandable to other modules

Flexible hardware/software configuration



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Room Air and Stack Monitoring system at Safety and Tritium Applied Research (STAR) facility

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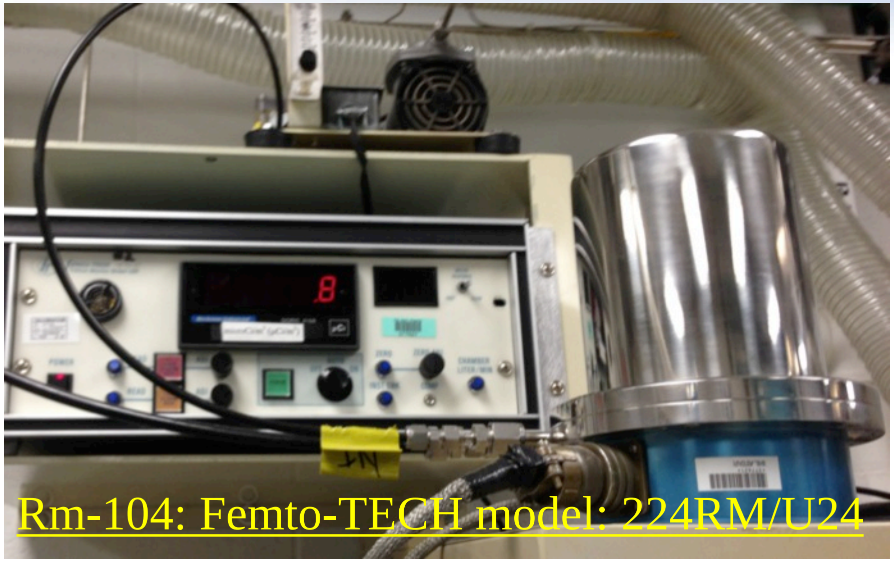
Upgrade to STAR Tritium Air Monitoring in FY15

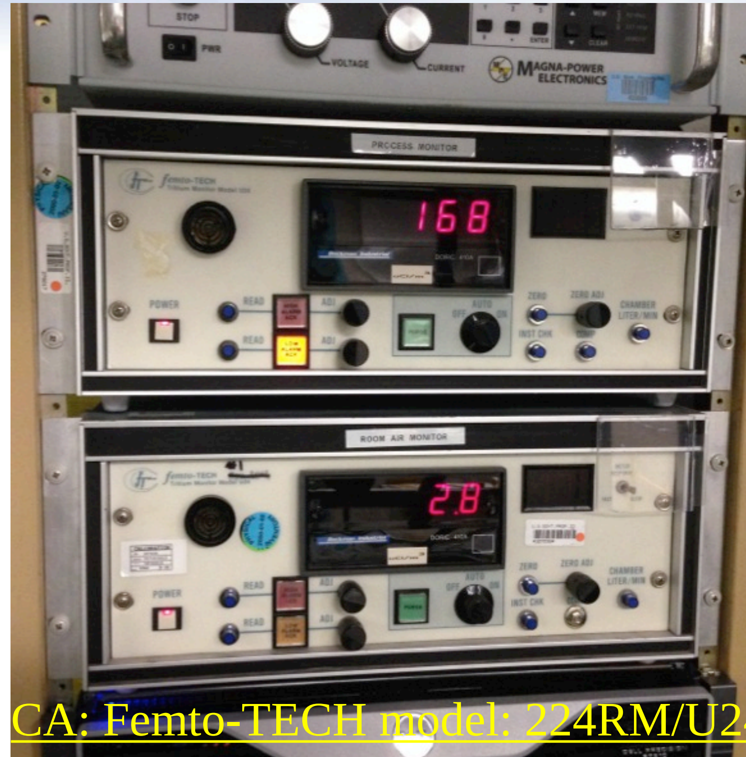
- During FY14 a planned power outage of 15 minutes took ~70 minutes due to technical difficulties
- A major component to STAR's tritium confinement strategy is its once through ventilation system.
- One of STAR's stack blowers was operating on site emergency power
- However, during this extended outage a temporary portable air monitor predicted a rise in tritium concentration in the STAR's tritium operation area
- It was later found that the air monitor was faulty but a very small tritium release could not be ruled out

Recommendation – enhance STAR's tritium air monitoring system not only for possible power outages, but to also gain a better understanding of the actually background tritium air concentration for worker safety

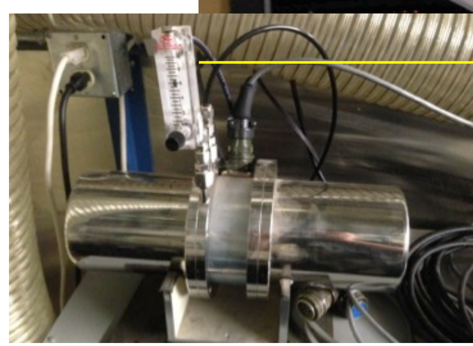
Existing Room Air monitoring in tritium area

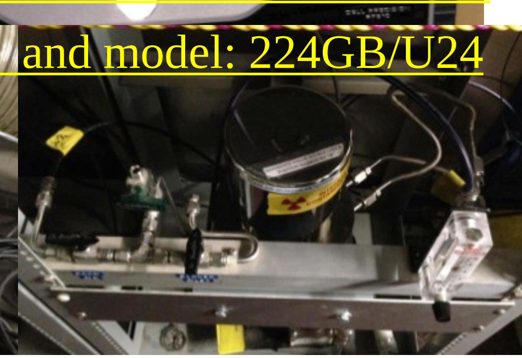


Rm-104: Femto-TECH model: 224RM/U24



CA: Femto-TECH model: 224RM/U24





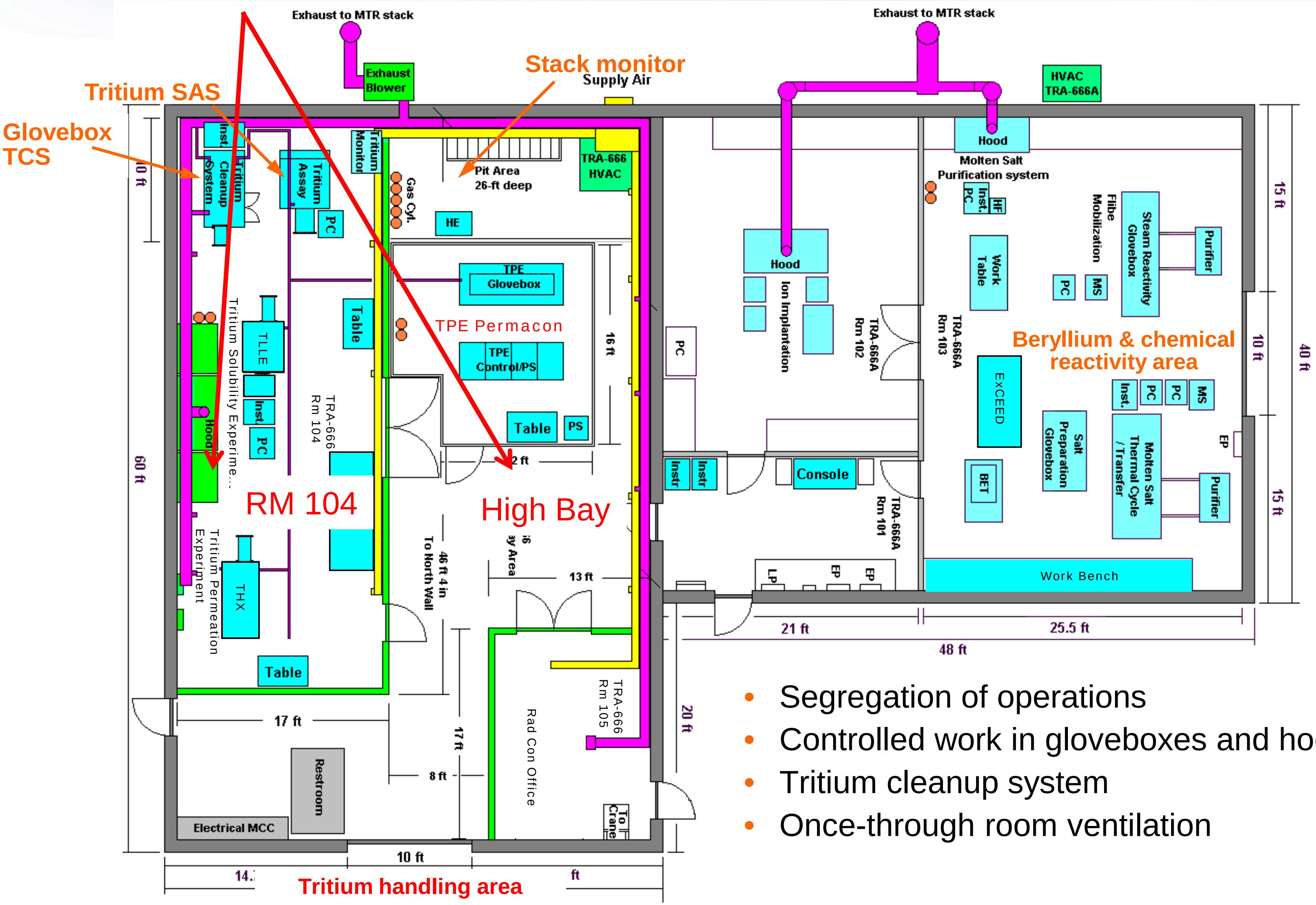
and model: 224GB/U24

- Continuous room air monitoring in now in STAR’s RM 104 and in Tritium Plasma Experiment’s (TPE’s) confinement area (CA)
- Resolution limit 0.1 μCi/m^3

Stack emission monitoring (from STAR facility):

- Continuous stacked air monitoring system
- Resolution limit 1x10^{-10} μCi/m^3
- Weekly release determined from integrated concentration in the bubbler vials

Additional Room Air Monitoring to be Added in STAR Tritium Operations Area in FY15



- Segregation of operations
- Controlled work in gloveboxes and hoods
- Tritium cleanup system
- Once-through room ventilation

Equipment to be added

- Mound Technical Solutions, Inc, model: MRB500 bubbler detectors will be added to RM104 and in the High Bay area just outside of TPE's CA.
- These monitors will be used to determine the weekly average tritium air concentration (expectation based on bioassey testing << $0.1\mu Ci/m^3$) in these area for worker dose estimates
- A Femto-TECH model: 224RM/U24 continuous air monitor will be placed in the High Bay area in front of TPE's CA at the location of the faulty monitor during the power outage
- Small UPS will be added to these monitors to handle brief power outages, but future plans include providing site emergency power to these monitors for extended power outages

Thank you!

Research challenge/questions

Fusion research challenge/Questions to be answered

1. What will be solved by ITER (TSTA, TFTR, JET) and what R&D is still needed?
2. What is the FES strategy for advancing the state of the art?
3. Which are the highest priorities for a program with a small budget?
4. What is the best morphology for a fusion breeding and extraction (Liquid PbLi, solid ceramic pebbles, nano-engineered structure)?
5. How do you validate breeder performance without a 14 MeV volumetric neutron source at the right flux/fluence?
6. What is the best way to collaborate and leverage the vast T experience base (labs, U, industry), for a science organization which publishes its research results and doesn't have access to the weapons program?
7. Which activities are the TFG able to provide data that will eliminate duplication?
8. Which new activities are the TFG interested in collaboration?
9. Which activities will answer questions needed for safe successful ITER operation?
10. What collaborations should take place on JET to maximize the knowledge capture during the last D-T volumetric fusion neutron source operations between now and ITER (2030+?
11. What are the lessons learned from past TFG activities in the public domain?

Research challenge/questions

1. What will be solved by ITER (TSTA, TFTR, JET) and what R&D is still needed?

- **There is a long way to go. ITER was discussed in the background slides, TFTR was shut down quickly, and the data is in 3-ring binders in boxes. FES is starting an initiatives to data mine the results with base program funds to LANL and INL. FES is reaching out to JET for collaborations on their D-T operations during 2017.**
- **In summary, we need advanced breeder materials, and the ability to handle, manage, and process tritium in large volumes very quickly to be recycled back to the fueling systems. Safety and tritium barriers are needed for tritium management and accountancy.**

Research challenge/questions

2. What is the FES strategy for advancing the state of the art?

- **The total annual budget last year in the fusion nuclear sciences, blanket, tritium, neutronics and safety program was approximately $4M.**
- **All these issues can't be solved on this budget, and the tritium-related work is less than half of this budget, mostly centered around Plasma Facing Component (PFC) and safety issues.**
- **We need to collaborate, to not "reinvent the wheel", and find partners with common needs and interests in and out of the fusion community.**
- **We seek to partner and leverage existing domestic and international facilities as opposed to building new facilities.**
- **We would benefit from research collaborations that can tackle common problems and address challenges with multi-institutional depth and expertise.**

Research challenge/questions

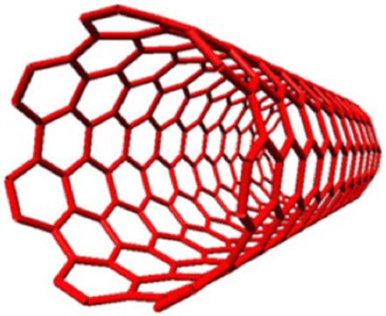
3. Which are the highest priorities for a program with a small budget?

- **Focus on niche areas where the US leads the world fusion community (specialization).**
- **Backstop ITER and find common interests that will help ITER succeed, while advancing the US fusion program. (New LANL collaboration on HPL, MELCOR, TMAP code support, TPE, THX, TGAP, TLLE are examples).**
- **Leverage off of existing programs and research developed for other applications (We are reaching out to this group).**
- **Ensure safe operations (TPE upgrades).**

Research challenge/questions

4. What is the best morphology for a fusion breeding and extraction (Liquid PbLi, solid ceramic pebbles, nano-engineered structure)?

- **Liquid PbLi has the highest temperature performance, but has corrosion, MHD, and pressure drop issues.**
- **Solid ceramic pebble beds are brittle, have high Hertzian stress at contact points, are sensitive to over-temp conditions and swelling under irradiation which leads to fracturing, and settling to the bottom of the containment chamber, which causes poor coolant flow, hot spots, then sintering.**
- **Recently completed SBIR funding** $150K (FY12)+ $1M (FY13-FY14) **made large strides in a new nano-structured solid breeder that avoids the problems of conventional solid breeders. It's too early to tell if it will meet all the requirements in the harsh fusion environment. The technology is seeking patent protection, so limited details here.**
- **Advancements in manufacturing carbon and metallic nano tubes compatible with lithium for lithium ion batteries could be a way to leverage advanced manufacturing and external investments.**



Research challenge/questions

5. How do you validate breeder performance without a 14 MeV volumetric neutron source at the right flux/fluence?

- **FES is has performed mechanical testing of the nano-engineered solid breeder material. Current tests are showing promising results.**
- **investigating several tests to simulate more realistic environments:**
- **Hydrogen testing at the LANL HPL (slides to follow).**
- **Tritium testing at INL**
- **In-pile testing at a fission Scientific User Facility (SUF), either HFIR (ORNL), or ATR (INL), or an international facility (possibly Japan?).**

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Research challenge/questions

6. What is the best way to collaborate and leverage the vast T experience base (labs, U, industry), for a science organization which publishes its research results and doesn't have access to the weapons program?

- **Collaboration either in a simple point-to-point mode, or in a more complex mode such as the BER model of Scientific Focus Areas (SFAs).**
- **A tritium consortium, composed of labs, universities, and industry could address common problems, with a multi-facility, multi-institutional approach. This has worked well for other SC projects in Biological Environmental Sciences (BER), such as the human genome project.**
- **Is there an interest for more collaboration in this group?**

Research challenge/questions

Fusion research challenge/Questions to be answered

7. Which activities are the TFG able to provide data that will eliminate duplication?
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9. Which activities will answer questions needed for safe successful ITER operation?
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