U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Initial Lithium Capabilities for NSTX-U and Plans for Mitigating Associated Risks*

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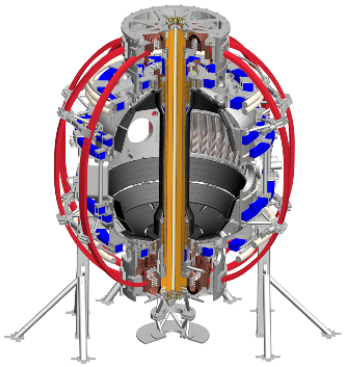
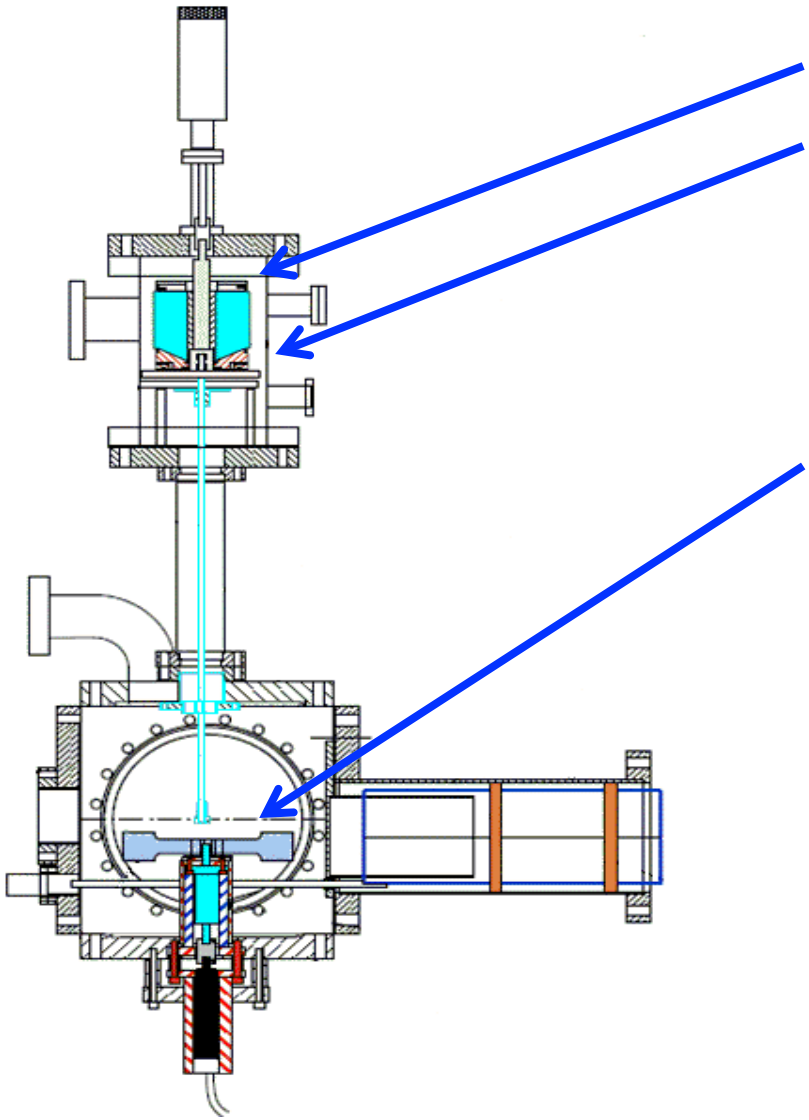
PPPL



Abstract

The effect on plasma performance of lithium plasma-facing components (PFCs) is an important research focus on NSTX-U. Lithium evaporators (LITERs) are mounted at two upper dome locations to evaporate lithium onto the lower divertor region. The introduction of lithium into NSTX-U will also be conducted by the injection of small granules from a lithium granule injector (LGI). The main risk for the LITERs and the LGI is commensurate to the state of the lithium. The lithium used in the LGI is in the form of solid, micron-sized granules, and relatively few granules would enter NSTX-U should any possible failure modes occur. Each LITER, however, can operate with up to 80 grams of liquid lithium. The PFC water-cooling lines will thus be emptied during lithium operations, to prevent exposure of liquid lithium to water if there is a simultaneous LITER structural failure and a water leak. If there is a simultaneous LITER structural failure and a large air leak, the graphite PFCs could then be subject to high heat from rapid lithium oxidation. The likelihood that it would cause serious PFC damage is being evaluated. A mitigation scheme is a gas purge system that fills the vacuum vessel with argon should there be a significant pressure excursion when the lithium is at elevated temperature.

Lithium use in NSTX-U includes granule injector for introducing small *solid* particles into plasmas



Granules housed within 4-chamber segmented dropper

Particle drop rates controlled by voltage applied to piezoelectric disk

Granules fall down guide tube and driven into plasma with pneumatic rotary impeller

Small total lithium inventory in typical chamber load
• 10 - 15 grams of *solid* lithium granules ranging from 300μm to 900 μm in diameter

See poster GP12.95 by R. Lunsford et al. for more details

Granules are primarily lithium with special coating

FMC Lithium

New Product Data Sheet

NPDS Ref. No: 642-098s
Version: US/Canada
Date Approved: 08/21/09
Revision No: 1

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:	Development Product 642-098
CHEMICAL FAMILY:	Alkali Metals
MOLECULAR FORMULA:	Li
GENERAL USE:	For Research and Development Use Only

MANUFACTURER
FMC CORPORATION
Lithium Division
P.O. Box 795
Bessemer City, NC 28016-0795
General Information: (704) 868-5300

Emergency Telephone Numbers:
Emergency Phone (704) 629-5361 (Plant) Call Collect 24 Hr/Day
Emergency Phone (303) 595-9048 (Medical) Call Collect

2. COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name	CAS #	Wt.%
Lithium metal	7439-93-2	90+
Trade Secret	not available	<10%

Solid lithium granules can be handled in air

HANDLING:

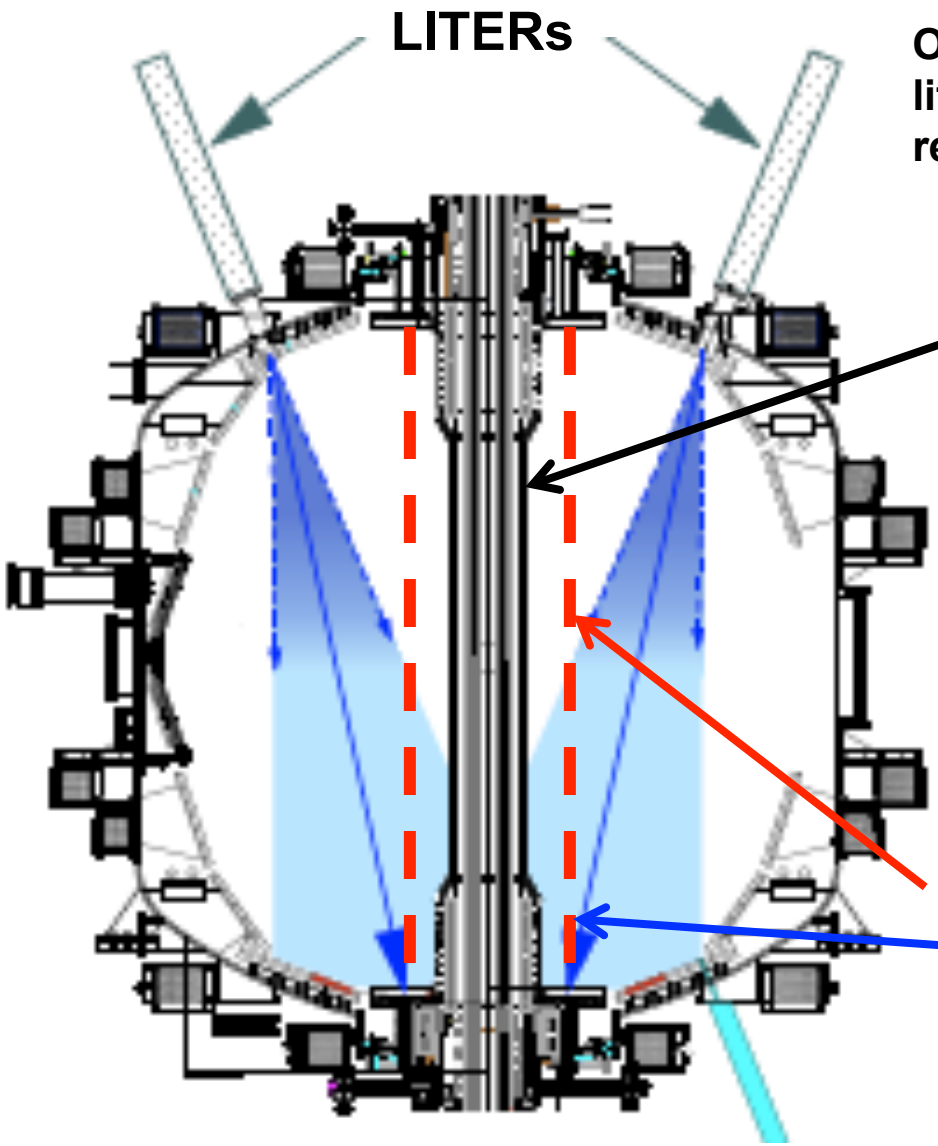
Can be handled in open atmosphere at room temperature, either coated with mineral oil or where relative humidity is maintained below 50%. To maintain best quality, humidity levels of less than 2% are recommended. Do not get in eyes, on skin or clothing. Avoid breathing dust. Wear safety glasses or goggles and dry rubber gloves.

STORAGE:

Store in original unopened shipping container. Once opened, store in argon atmosphere or mineral oil. Keep away from water, humid air, acids and oxidizing materials. Keep away from heat, sparks and flame.

General practice is still to transfer lithium granules from shipping container to granule injector housing under argon atmosphere to minimize oxidation

Lithium evaporators – LITERs – continue to be primary means of coating PFCs in NSTX-U

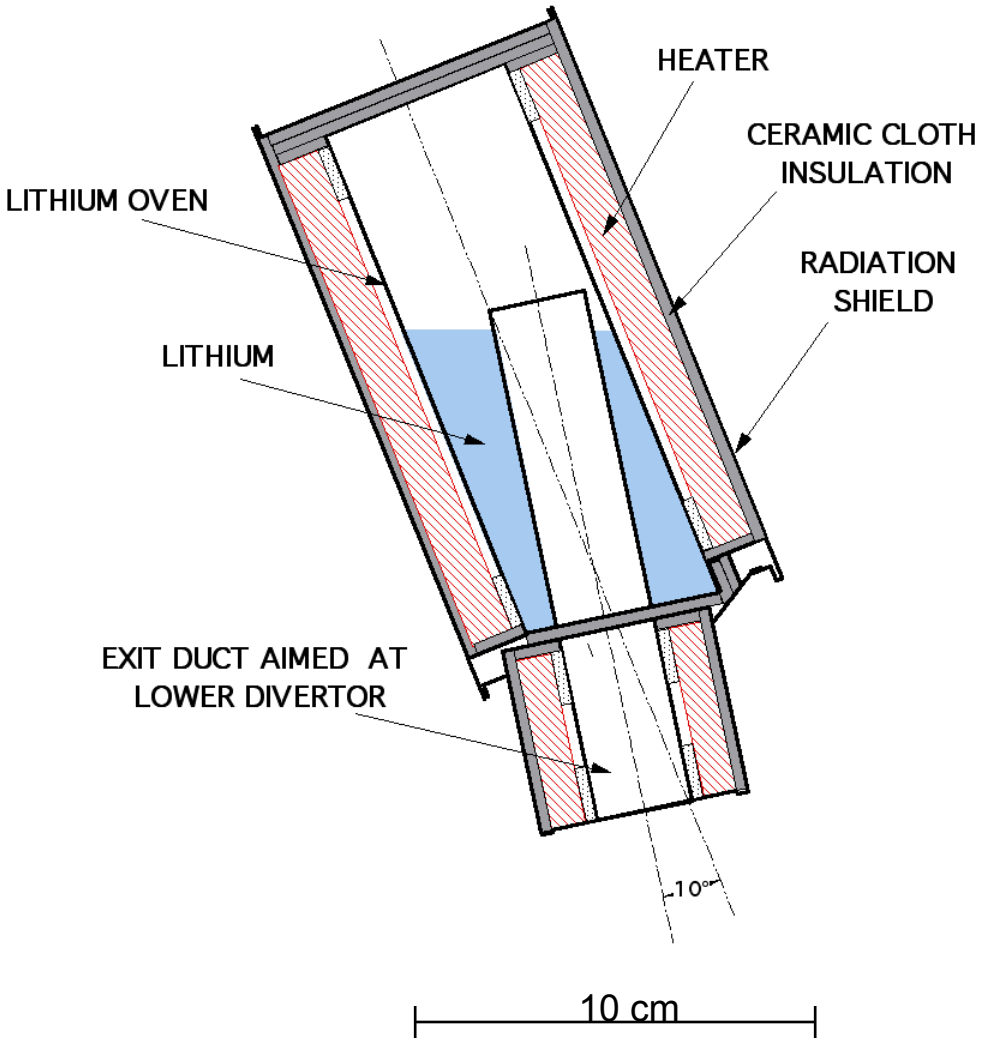


Orientation of exit tubes for lithium evaporators – LITERs – to remain unchanged for NSTX-U

Original NSTX center stack

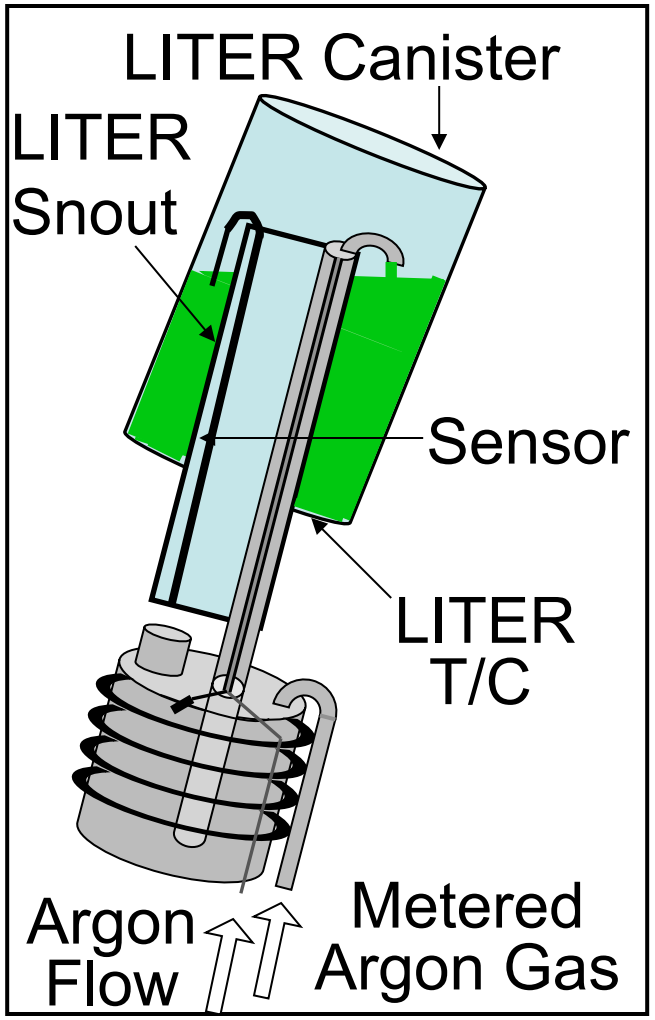
- Larger diameter of new center stack
  - More lithium coverage for "vertical" section of inboard divertor

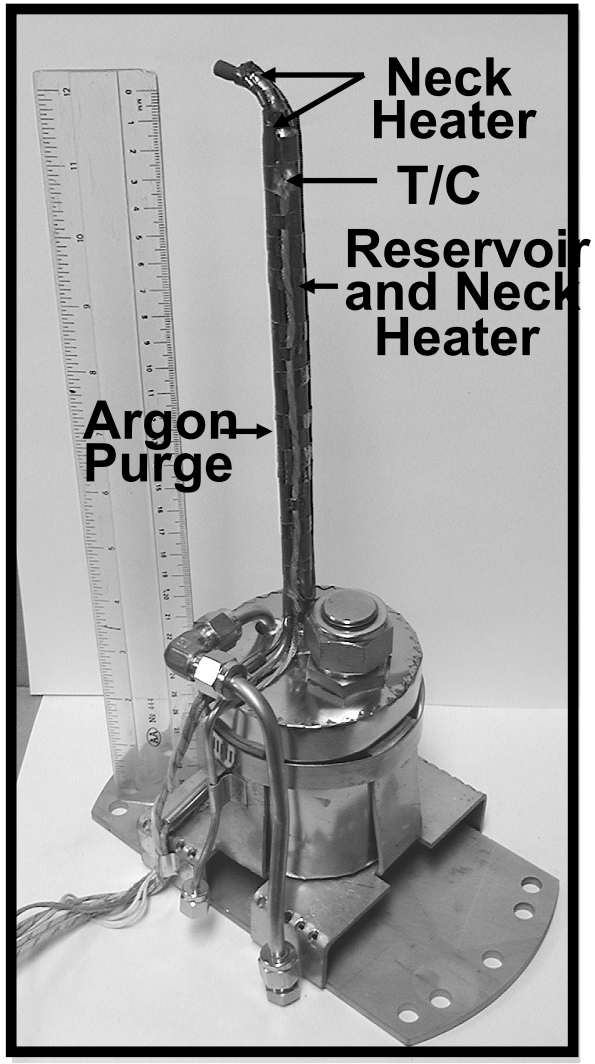
Liquid lithium in LITERS is primary safety concern



- **Typical load: 80 g of Li**
- **Oven Temp: 600-680°C**
- **Rate: 1mg/min - 80mg/min**

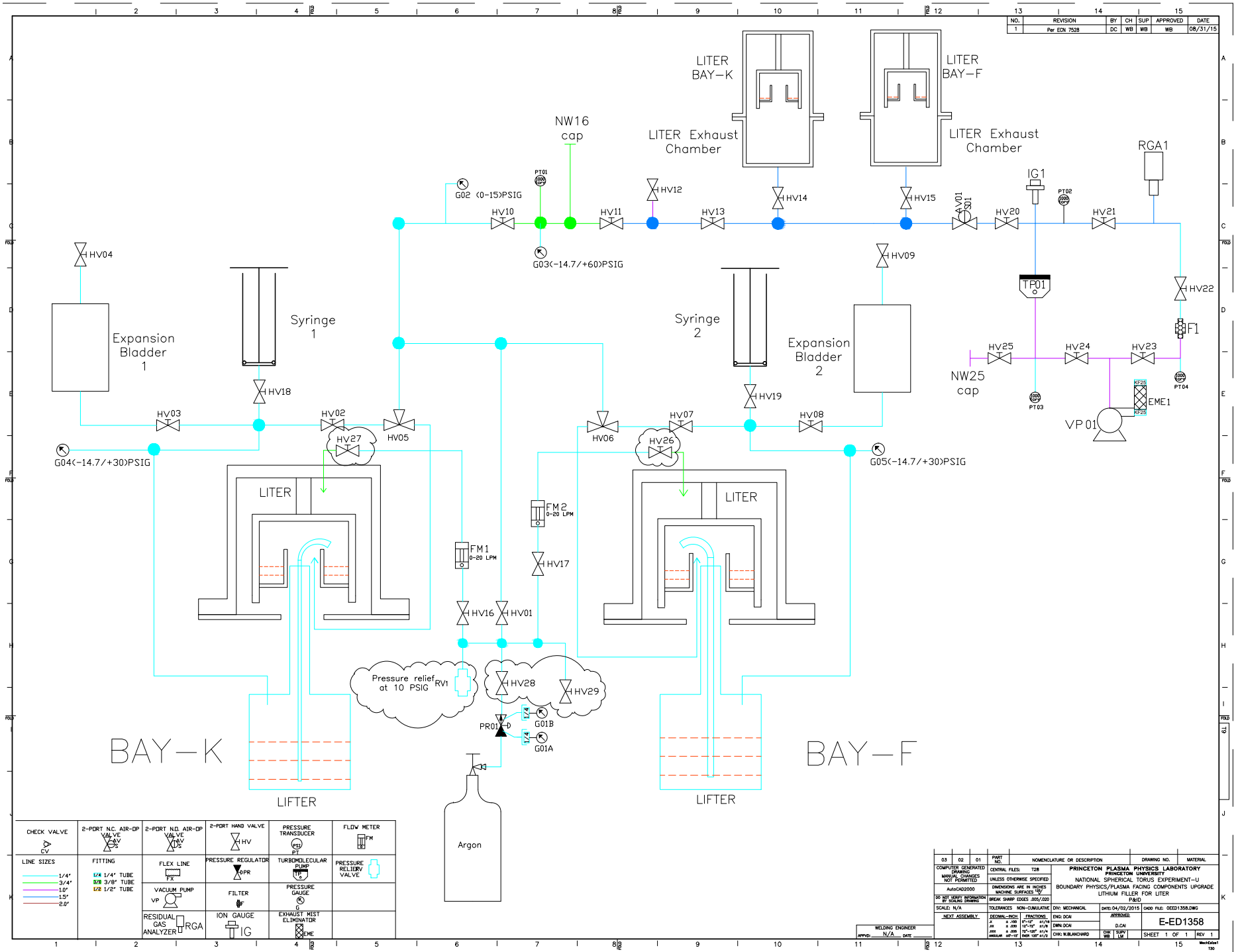
LITER filling performed most efficiently with *liquid* lithium using Lithium Filler for LITER – LIFTER





LIFTER loading station shows two LITERs with probe drives

Revised procedures plus new piping and instrumentation diagram – PID – improves LIFTER safety since last used during NSTX operations


LITER BAY–K
LITER BAY–F
LITER Exhaust Chamber
LITER Exhaust Chamber
NW16 cap
RGA1
IG1
G02 (0–15)PSIG
G03(–14.7/+60)PSIG
HV10
HV11
HV12
HV13
HV14
HV15
HV20
HV21
HV22
PT01
PT02
PT03
PT04
TP01
F1
HV04
Expansion Bladder 1
Syringe 1
Syringe 2
Expansion Bladder 2
HV09
HV18
HV19
HV25
HV24
HV23
NW25 cap
EME1
VP 01
HV03
HV02
HV05
HV06
HV07
HV08
HV27
HV26
G04(–14.7/+30)PSIG
G05(–14.7/+30)PSIG
LITER
LITER
FM 2 0–20 LPM
FM 1 0–20 LPM
HV17
HV16
HV01
Pressure relief at 10 PSIG
RV1
HV28
HV29
PR01
G01B
G01A
1/4
1/4
BAY–K
BAY–F
LIFTER
LIFTER
Argon
CHECK VALVE
CV
2-PORT N.C. AIR-OP VALVE
2-PORT N.O. AIR-OP VALVE
2-PORT HAND VALVE
HV
PRESSURE TRANSDUCER
PT
FLOW METER
FM
LINE SIZES
1/4"
3/4"
1.0"
1.5"
2.0"
FITTING
1/4 1/4" TUBE
3/8 3/8" TUBE
1/2 1/2" TUBE
FLEX LINE
FX
PRESSURE REGULATOR
PR
TURBOMOLECULAR PUMP
PRESSURE RELIEF VALVE
VACUUM PUMP
VP
FILTER
F
PRESSURE GAUGE
G
RESIDUAL GAS ANALYZER
RGA
ION GAUGE
IG
EXHAUST MIST ELIMINATOR
EME
NO. REVISION BY CH SUP APPROVED DATE
1 Per ECN 7528 DC WB WB WB 08/31/15
PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT–U
BOUNDARY PHYSICS/PLASMA FACING COMPONENTS UPGRADE
LITHIUM FILLER FOR LITER
P&ID
DATE: 04/02/2015
CADD FILE: GEED1358.DWG
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SHEET 1 OF 1
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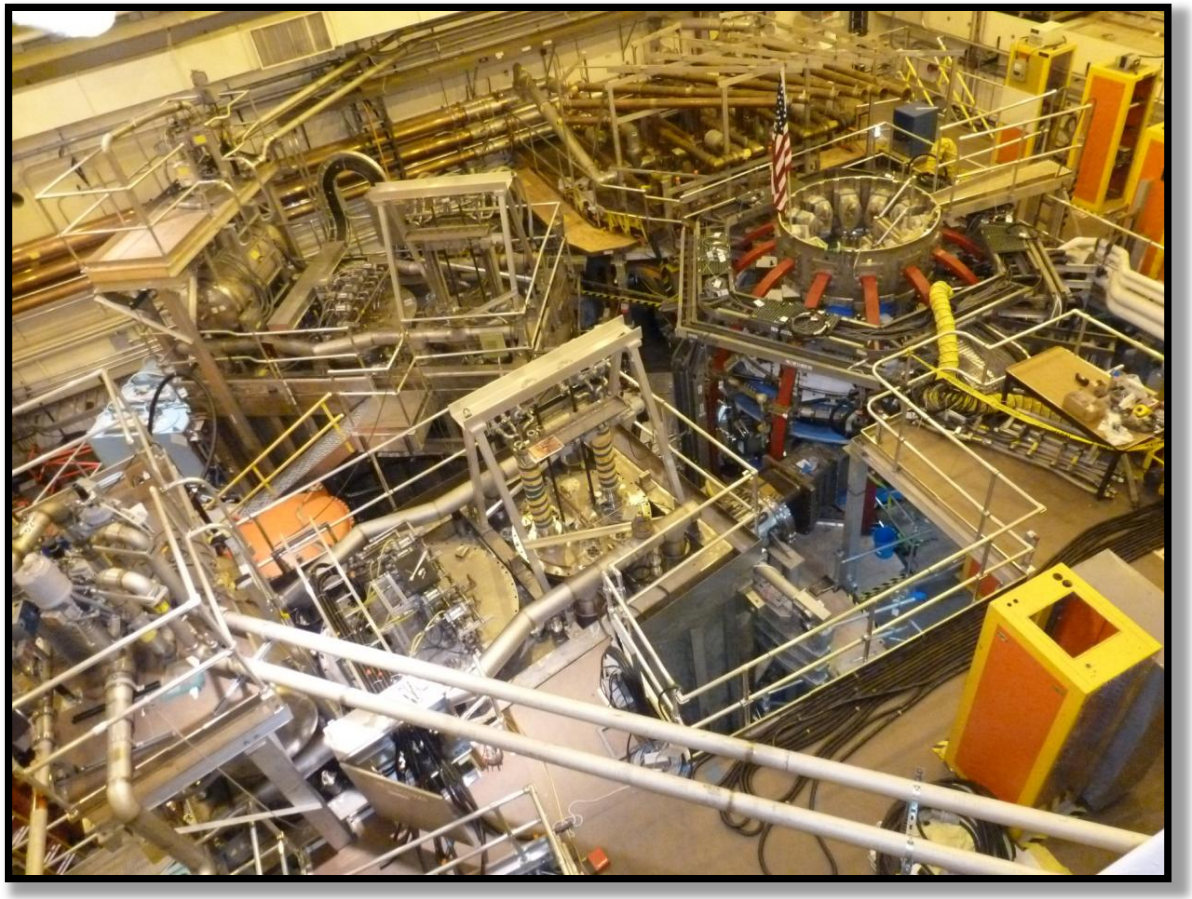
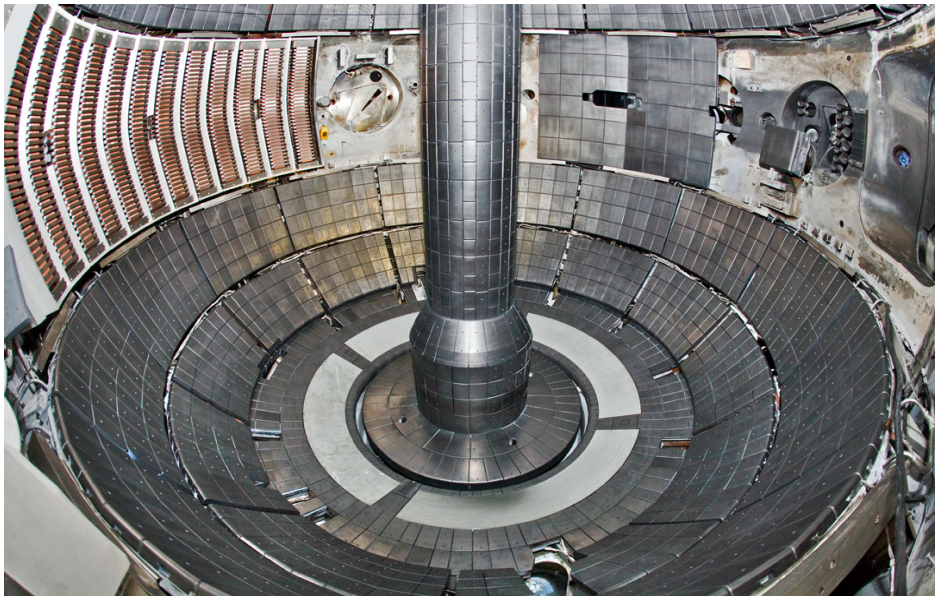
New requirements and safety systems being implemented to improve lithium safety on NSTX-U

- **Water lines internal to vacuum vessel for cooling PFCs emptied when lithium operations begin**



Continued presence of graphite tiles in NSTX-U motivated further failure mode assessment

Photograph of NSTX interior showing graphite tiles forming passive plate and divertor surfaces



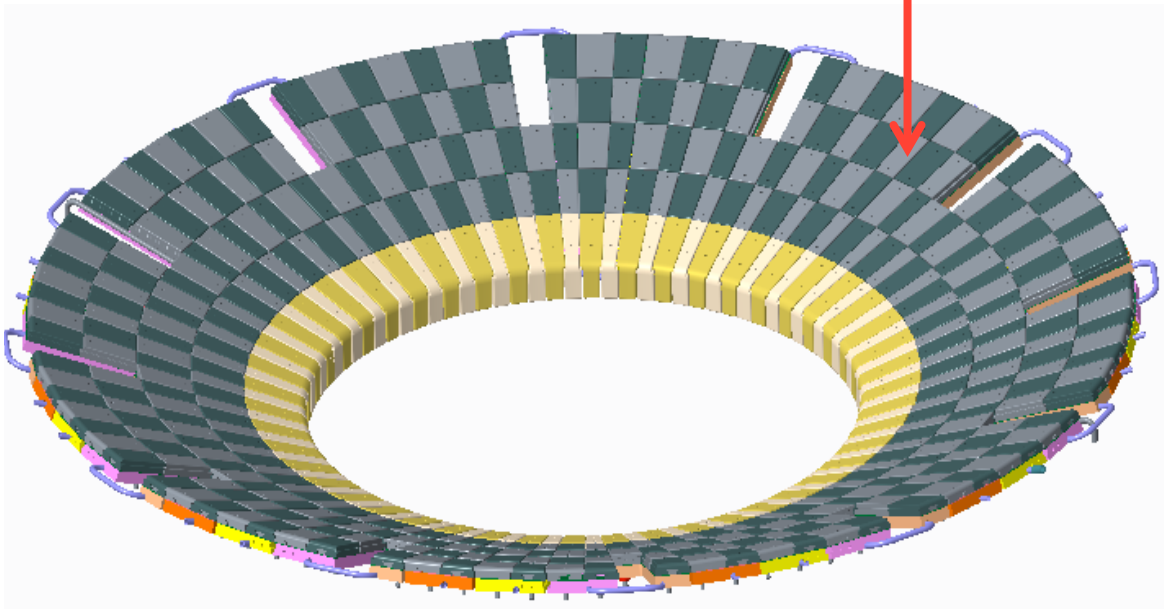
Lighter colored surface depicts molybdenum-coated "ring" that formed substrate for liquid lithium on outer divertor in NSTX – ***geometry of outer divertor unchanged in NSTX-U***

Failure mode assessed with simplified geometry of LITER above graphite tiles

Cylindrical liquid lithium stainless steel container - 2.25” OD and 2” I.D. - that holds about 80 grams of liquid lithium

2.25” diameter

Distance between bottom of lithium container to graphite tiles is about 95”



LITER failure mode evaluated

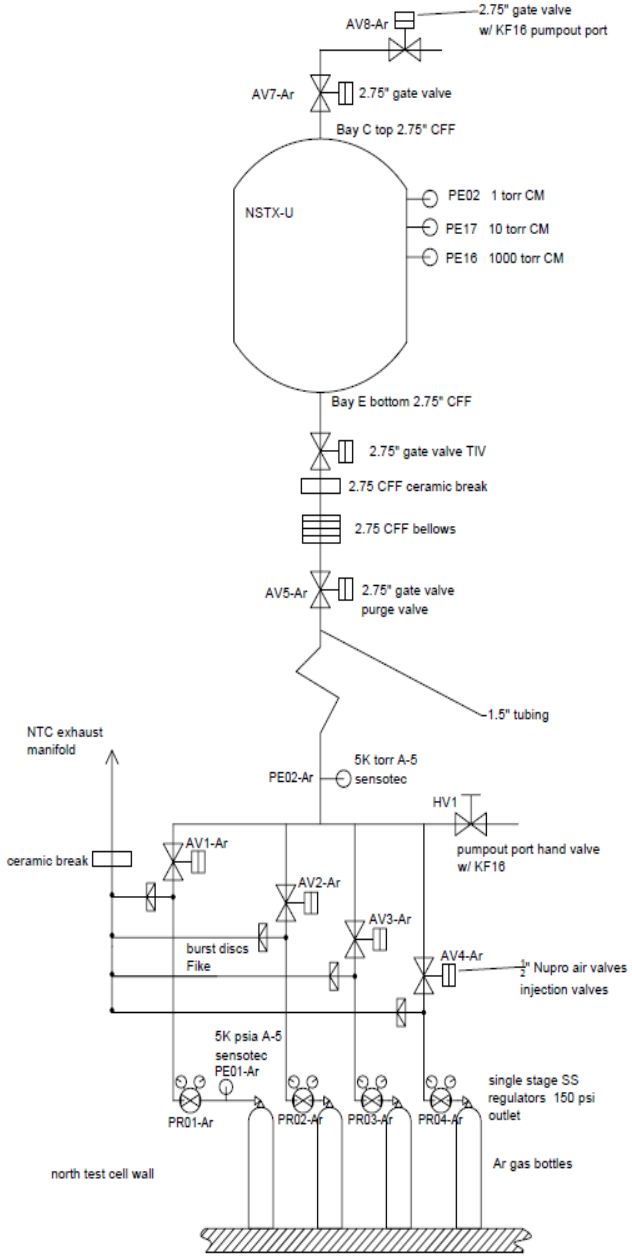
- **Assume following events occur *simultaneously***
  - **Structural failure of LITER with liquid lithium at 600^{o}C causes entire 80 g inventory to fall on graphite tiles from height in preceding figure**
  - **Loss of vacuum from rupture of 8”OD/6”ID window causes inrush of air**

Conclusions from failure mode assessment

- "Runaway" combustion of carbon tiles extremely unlikely
  - Very low viscosity means liquid lithium spreads and distributes heat over tiles
- Implementation of mitigation scheme still recommended
  - Potentially serious consequences of extremely low probability event justifies mitigation effort
  - Straightforward and cost effect scheme proposed

Argon purge system being implemented as mitigation measure at modest effort and cost

- Four parallel argon cylinders @ ~ 2700 PSI
- Cylinders located inside NSTX-U test cell
- Inlet at bottom of vacuum vessel
- Outlet at top of vacuum vessel
- 1.5” OD delivery line between cylinders and inlet
- Two pressure gauges:
  - Cylinder pressure
  - Line pressure
- System enabled when LITERs are at operating temperature
- Triggered in event of loss of vacuum


AV8-Ar
2.75" gate valve
w/ KF16 pumpout port
AV7-Ar
2.75" gate valve
Bay C top 2.75" CFF
NSTX-U
PE02 1 torr CM
PE17 10 torr CM
PE16 1000 torr CM
Bay E bottom 2.75" CFF
2.75" gate valve TIV
2.75 CFF ceramic break
2.75 CFF bellows
AV5-Ar
2.75" gate valve
purge valve
1.5" tubing
NTC exhaust
manifold
PE02-Ar
5K torr A-5
sensotec
HV1
pumpout port hand valve
w/ KF16
ceramic break
AV1-Ar
AV2-Ar
AV3-Ar
AV4-Ar
burst discs
Fike
½" Nupro air valves
injection valves
5K psia A-5
sensotec
PE01-Ar
PR01-Ar
PR02-Ar
PR03-Ar
PR04-Ar
single stage SS
regulators 150 psi
outlet
north test cell wall
Ar gas bottles

Conclusions

- Lithium expected to play key role in NSTX-U program
- Quantity and use of lithium as solid in granule injector not expected to be major safety concern
- Improvements in lithium handling practices and new methods for mitigating risks related to liquid lithium being implemented
  - Includes insuring absence of water cooling inside NSTX-U vacuum vessel during LITER operations
  - Argon purge system being installed to mitigate effects of simultaneous structural failure of LITER filled with liquid lithium and loss of NSTX-U vacuum