TRIUMF

Liquid Helium Consumption and Availability

Chris Gibson

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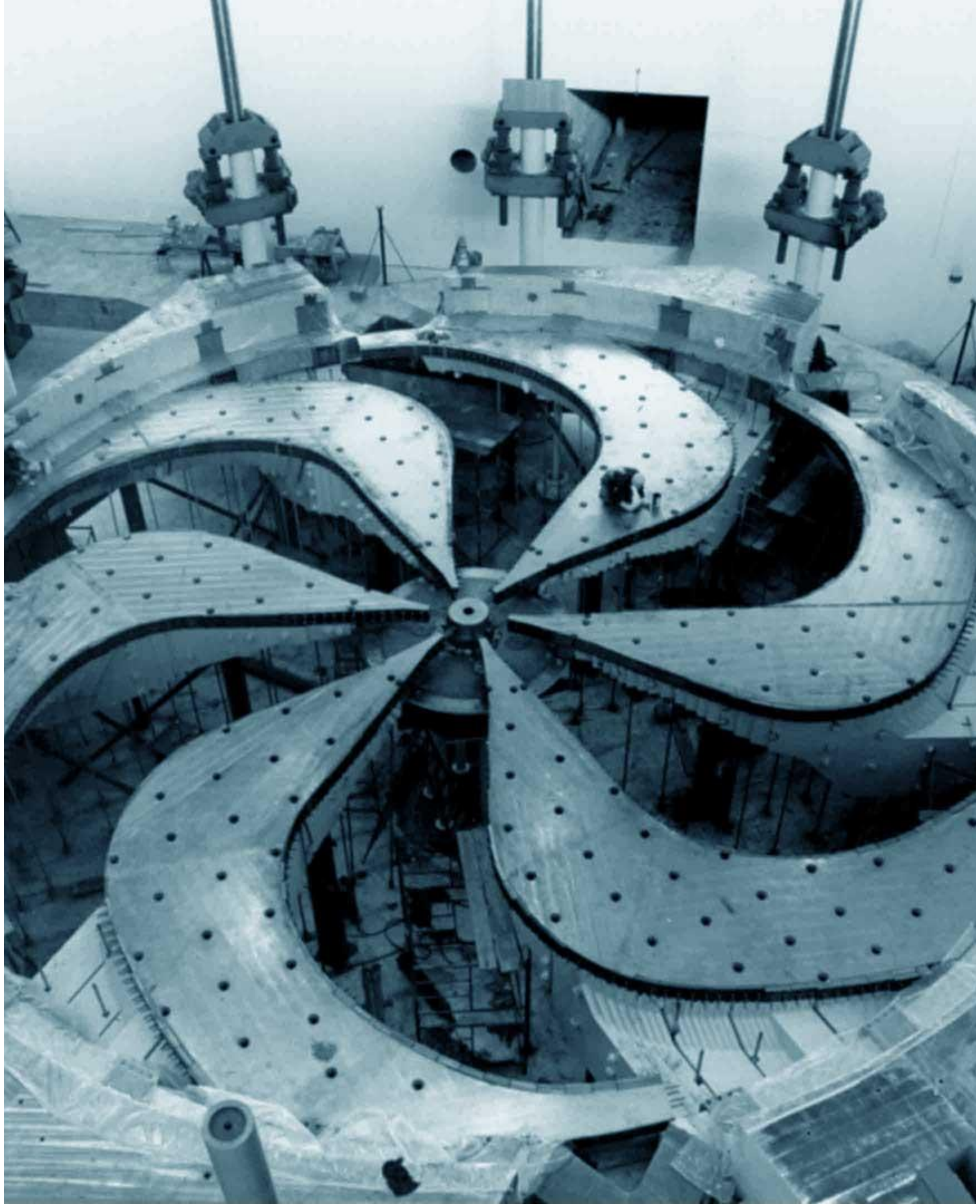

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Contents

Requirements (Details here*)

Applicable requirement (From He Cryostat Requirements Document):

RS 2.1-4 Shall cool within delivered helium mass flow and supply line pressure drop budgets*

- Details (flows, temperatures, etc.) of requirements or constraints at interfaces as specified in the UCN Specification Sheet (Document-157233)

- Initial expectations were:
  - Existing facility capability ~50L/h
  - Beam on target (30-90 seconds): <100L/h
  - Average over experimental cycle (3-6 minutes): <35L/h
  - 24h average during experiment operation: <35L/h
  - Scheduled temporary high-rate consumption: up to 800L over 10h
  - Other users 5-15 L/h

Description of Analysis Performed to Validate Requirement and Determine Compliance

- An operational model was created to simulate Helium usage for UCN and other users.
- Excel worksheet with macros (Visual Basic for Applications) used to create the model
- Various inputs to the model were required - shown on next slide
- A baseline duty cycle for beam on/off timing was assumed – described later

Inputs to the Model

The following inputs were gathered to construct the model:

- Liquefier facility schematic, capabilities, and operation modes
- Schematic of the natural helium circuits of the new source including He recovery system and Schematic showing shield cooling flows.
- Expected usage requirements of other experiments (number of dewar fills per week)
- Helium cryostat natural helium consumption profile based on cryogenic calculations and a system-level optimization of configuration and duty cycle for optimal statistical sensitivity per measurement time See references on this slide of the appendix.
- Note that the cryostat helium consumption is determined by the sum of the natural helium pumping speed lowering the temperature of the 1K pot (0.49 g/sec) and the total 4K bath boil-off requirement (1.213 g/sec); the total boil off requirement is the sum of the necessary HEX7 flow, cooling the incoming 3He (0.747 g/sec) and the thermal shield cooling flow requirements (0.466 g/sec).
- Transfer losses for liquid transfers (7% for Helium fill line, 20% for user Dewar fills)

Baseline Cycle Description

The baseline EDM experimental cycle used for the analysis was:

- 16-hour beam-on day (13 weekday, 24 weekend, due to magnetic fluctuation during the day*)
- No irradiation while UCNs are emptying. (Conservative assumption due to the unknown effect on detector background)
- 1 experiment cycle = 2 minutes beam-on with 8.1W prompt heating, 4 minutes beam-off, for a duty cycle of 33% see also paragraph 5.2 (optimization) of Conceptual Design Report for the Neutron Electric Dipole Moment Experiment at TRIUMF.
    - Uses 49 L/h liquid He during this mode
- Cryostat goes into stand-by mode during daytime which lowers consumption, but which requires 1.6 hours to cool-down prior to re-start of experimentation in the evening.
    - Uses 18 L/h liquid He during this mode

* Reasons for assuming no experiment during weekday daytime discussed in talk 6.1 (Wolfgang Schreyer)

Main macro sheet showing model inputs and outputs

Legend
Guess/High Uncertainty Number
Currently Calculated
Modified by Macro
Read by Macro (Fixed or Calculated)

HP Storage
Level: 1701 Liquid L eq
Max Level: 4009 Liquid L eq
Min Level: 542.5

Liquifier: Ready
UCN: Ready
Inventory: 4009

Other System Transfer Losses and Returns: 0 g/sec

Recovery Comp.
Flow: 4.08 g/sec
Max Flow: 4.08 g/sec

Recovery Bag
Temp: 300 K
Pressure: 101.3 Kpa
Level: 22.2 Liquid L eq
Max Level: 50 Liquid L eq
Min Level: 5 Liquid L eq
Pump Trigger: 30 Liquid L eq

Liquifier
Gross Flow: 2.441 g/sec
Max Gross Flow: 2.441 g/sec = 70.0 L/h
Max Transfer Loss: 0.000 g/sec
Net Max Flow: 2.441 g/sec = 70.0 L/h

UCN 4K Boil Off
Flow: 1.213 g/sec

Total return from Other Users
Flow: 0.390299 g/sec

Mother Dewar
Temp: 4.5 K
Pressure: 130 kPa
Level: 757 L
Max Level: 900 L
Min Level: 100 L

Volume of Fill Line: L
Max Gross Flow: 2.5 g/sec
Gross Flow: 2.5 g/sec
Temp: 4.5 K
Pressure: 130 kPa
Max Filling Loss: 0.249 g/sec
Net Max Flow: 2.251 g/sec — 35.1 L/h

Average UCN: 39.0 L/h

Pumps
Max Flow: 0.49 g/sec
Flow: 0.49 g/sec

Flow: 0 g/sec
Max Filling Flow Rate: 5.086343 g/sec
Transfer Loss: 1.017269 g/sec
Net Filling Flow: 4.069074 g/sec — 11.9 L/h

Average CMMS: 14.8 L/h

4K Bath
Temp: 4.2 K
Pressure: 101.3 kPa
Level: 156 L
Max Level: 180 L
Min Level: 100 L

Volume Incl HEX5 L
Isopure Heat (W)
3He Heat (W)

Transfer Dewars
Number in Service (>20L): 6
Total Level: 1363.8 L
Max Level Per Dewar: 350 L
Transfer Loss Per Dewar Fill: 87.5 L

Scan Through Year | Initialize

Max Flow: 1 g/sec
Flow: 1 g/sec
Temp: 3 K
Pressure: 98.8 kPa

Date & Time: Sunday, December 19, 2027 — 12:05 AM

TimeStep: 5 minutes
Animate Charts?: No
Disable Calc and Screen Updates?: No

Isopure Feed Heat (W)
3He Feed Heat (W)

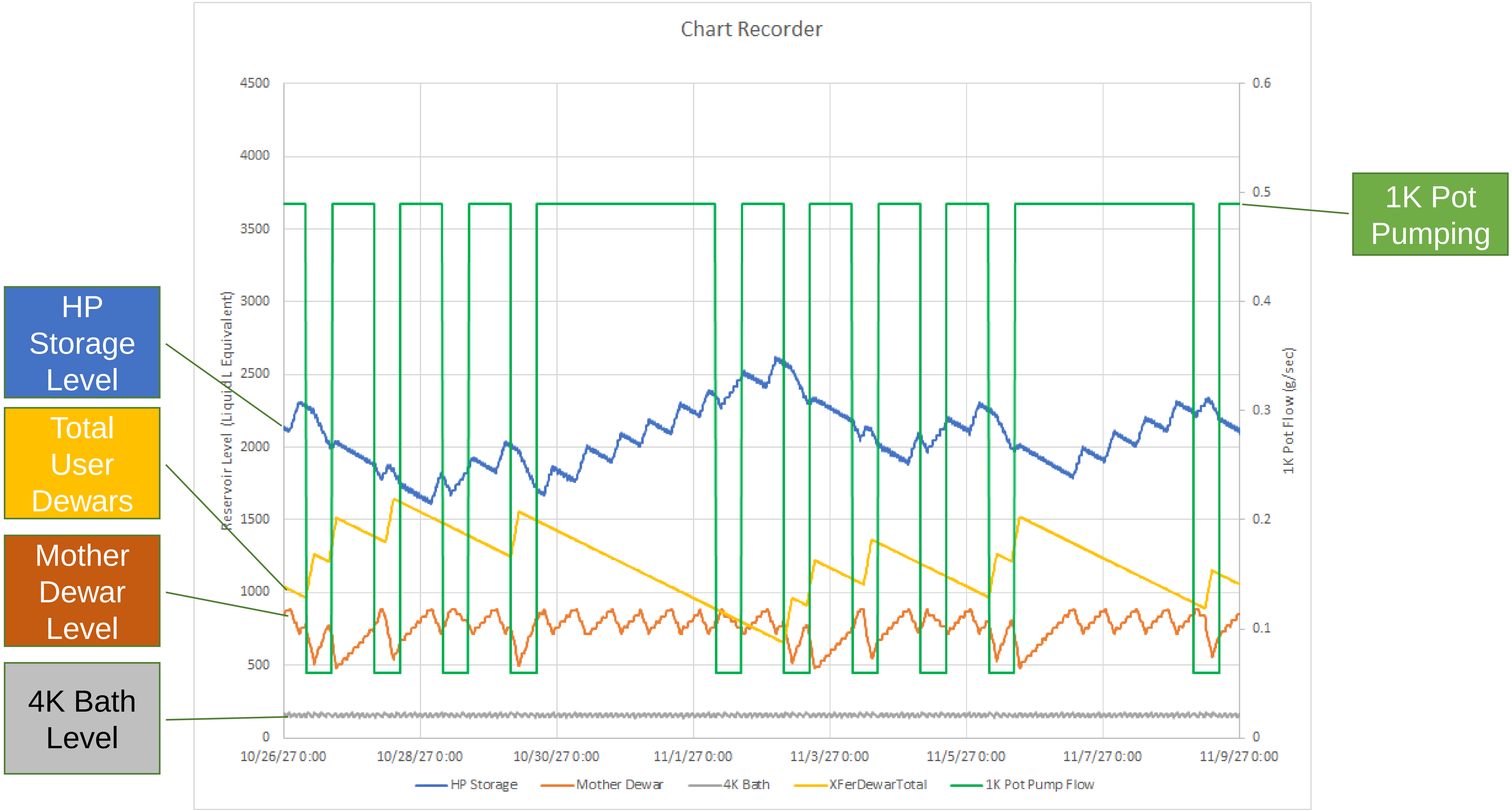
1K Pot
Temp: 1.6 K
Pressure: 0.75 kPa
Level: 8.6 L
Max Level: 10 L
Min Level: 5 L

IMPORTANT UCN SOURCE ASSUMPTIONS

Static + Beam Heat Hourly Beam-on Average:	4.5	W
Resultant average flow:	1.703	g/sec
Static Heat Load:	1	W
Resultant average flow:	0.633	g/sec
4K boil-off requirement during Static + Beam-on Average:	1.213	g/sec (49 L/h)
4K boil-off Requirement Static Heat Load:	0.573	g/sec (18 L/h)
1K Pot Pumping Speed during Static + Beam-on Average:	0.49	g/sec
1K Pot Pumping Speed Static Heat Load:	0.06	g/sec
Helium Density at 300K, 1 atm	0.16256	g/L
Helium Density at 4K, 1 atm	125.56	g/L
Helium Density at 300K, 5294 psi	50.2	g/L

VBA Code does calculations, Excel sheet has model inputs and outputs

Model outputs over 2-week period



Results of Analysis with Baseline Duty Cycle

- The current Facility cannot support the new UCN experiment at the same time as all other CMMS users
- Annual Helium loss estimated to cost ~$80K/year
- Any downtime of the Helium facility outside of main shutdown would reduce the UCN uptime significantly
- Downtime during scheduled maintenance days and mini-shutdown could somewhat impact UCN uptime, because model assumes that UCN source and Helium Facility operate in beam-off mode during these times

Minimum Required Facility improvement to support all users and nEDM Experiment[1] are:

- RSX compressor upgrade increasing maximum flow to 70 LPh
- Small increase in HP storage of 200L Liquid equivalent
- Running a more aggressive duty cycle would require additional upgrades

Link to operational model (case 1):
https://ucn.triumf.ca/triumf/project-management/p0407-ucn-electric-dipole-moment-project-plan-files/records-of-deliverables/FIllerUpRSXUpgrade.xlsm/view

1. Conservative: 16-hour day (13 weekday, 24 weekend), no irradiation while emptying. 1 cycle = 2 minutes beam-on with 8.1W prompt heating, 4 minutes beam-off. Cryostat goes into mode during daytime which lowers consumption, but which requires 1.6 hours to cool-down prior to re-start of experimentation in the evening. Estimated days-to reach (August 2019 simulation) = 458.
An upgrade to ~100-120L per hour could accommodate more aggressive nEDM Experiment operation, such as 2 minutes beam-on, 2 minutes beam-off, OR running during weekday day-shifts which could improve days-to reach
(see next 2 slides)

Results: Analysis Scenario - Run Experiment Within Limits of Existing Facility

Impact on nEDM Experiment[2] to run within envelope of current facility would be increase in Days to Reach: 10

	Baseline	Limited
Average He Consumption Apr 24 to Dec 18	39 L/h	24 L/h
Days to Reach	458	900-1200*

* 3 calendar years extra

Link to operational model (case 2):
https://ucn.triumf.ca/triumf/project-management/p0407-ucn-electric-dipole-moment-project-plan-files/records-of-deliverables/FIllerUpReducedBeamPower.xlsm/view

Note that the exercise of creating the dynamic model invalidated the original requirement somewhat. The requirement was based on ~15L for CMMS, ~30L for He Cryostat on average. In reality, with transfer dewar filling losses, CMMS sometimes consumes 17-19L/h averaged over several weeks, and the He Cryostat has higher consumption than its average over the weekend, so in order to accommodate various peak flows, the May-December average consumption of the He cryostat actually needs to be <25L/h to operate within the current 50L/h liquefier capability.

2. Conservative: 16-hour day , no irradiation while emptying. 1 cycle = 2 minutes beam-on with 5.4W prompt heating, 8-10 minutes beam-off (26 L/h liquid He usage in this mode).
Cryostat goes into mode during daytime which lowers consumption, but which requires 1.6 hours to cool-down prior to re-start of experimentation in the evening (18 L/h liquid He usage in this mode).

Actions – For Source Gate 2

- Investigate whether CMMS future usage could be lower than assumed.
- Proceed with design (maximizing efficiency where possible), but escalate issue to PMOG to highlight that a facility upgrade project should be kicked off ASAP; this should be a formal PMOG project since proper stakeholder requirements need to be gathered and resultant facility should meet all requirements (likely including reduced labor to operate).

Summary

- The detailed study indicated that existing Facility is not adequate for nEDM data taking (subject to verification with installed cryostat)

- RSX upgrade may only be temporary solution:
  - What if we want to increase our duty cycle?
  - 2nd experiment running in parallel?
  - Facility requires significant manpower to run

- For the reasons above, a new facility could be the only option to enable a competitive experiment

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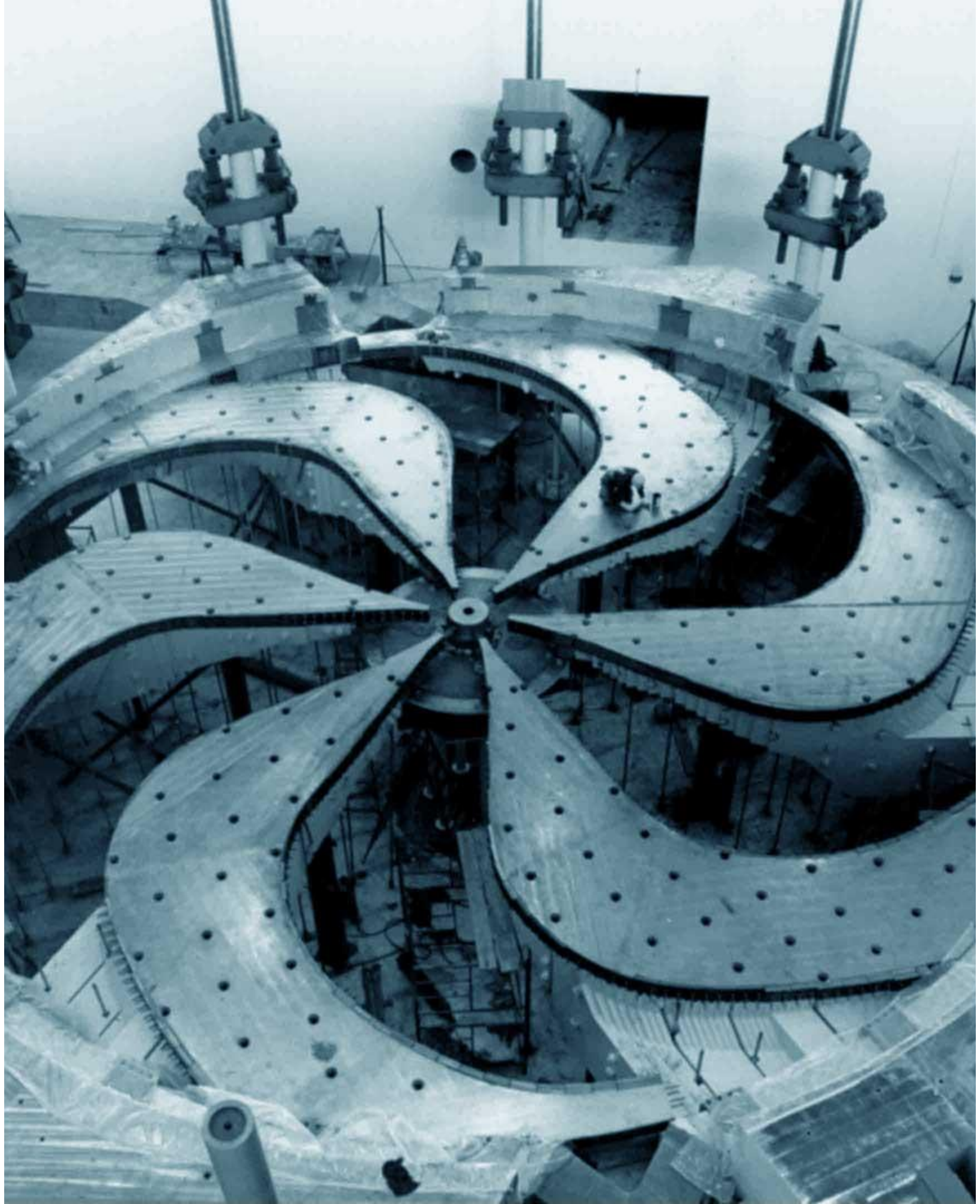
Appendices



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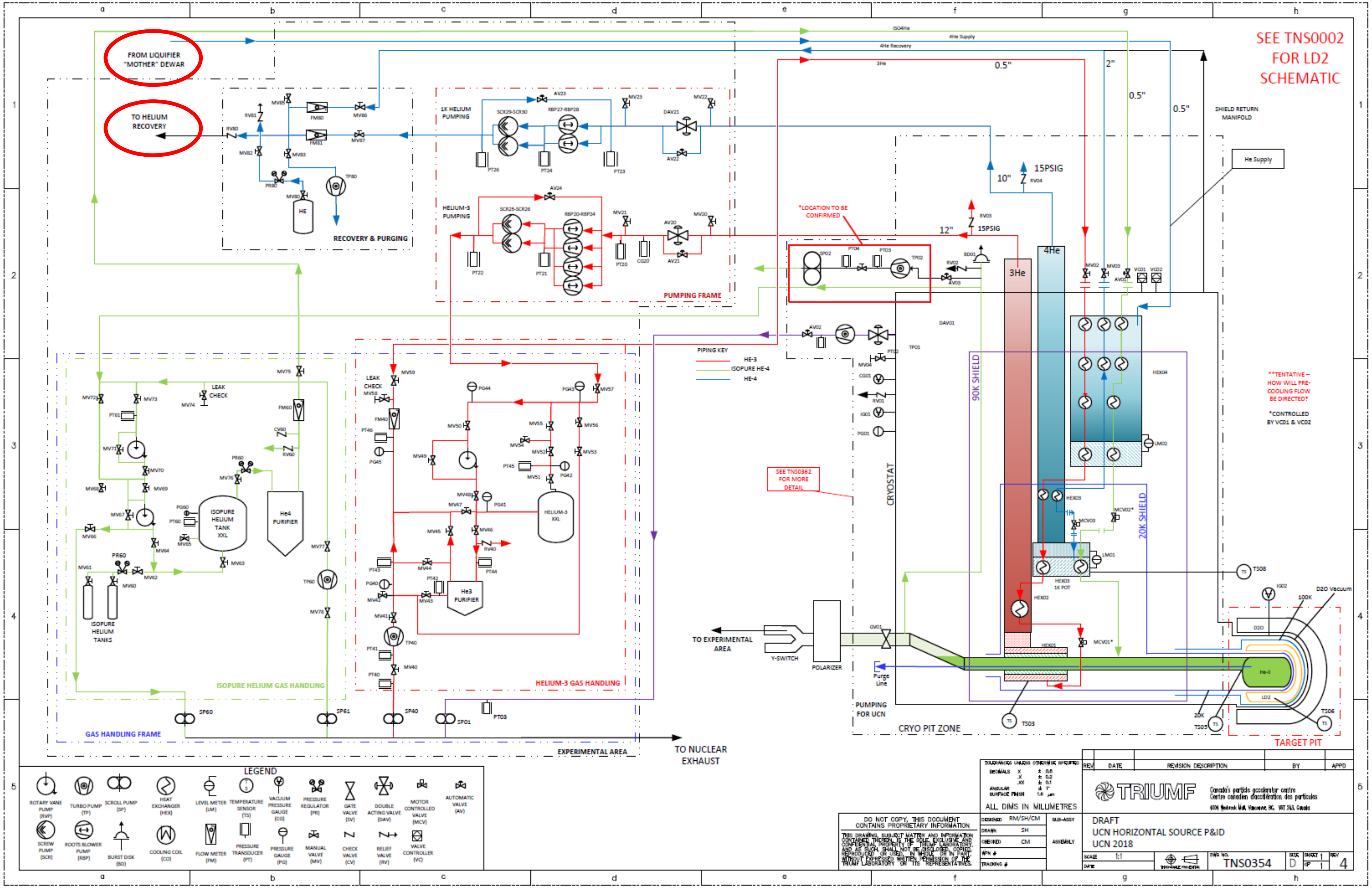
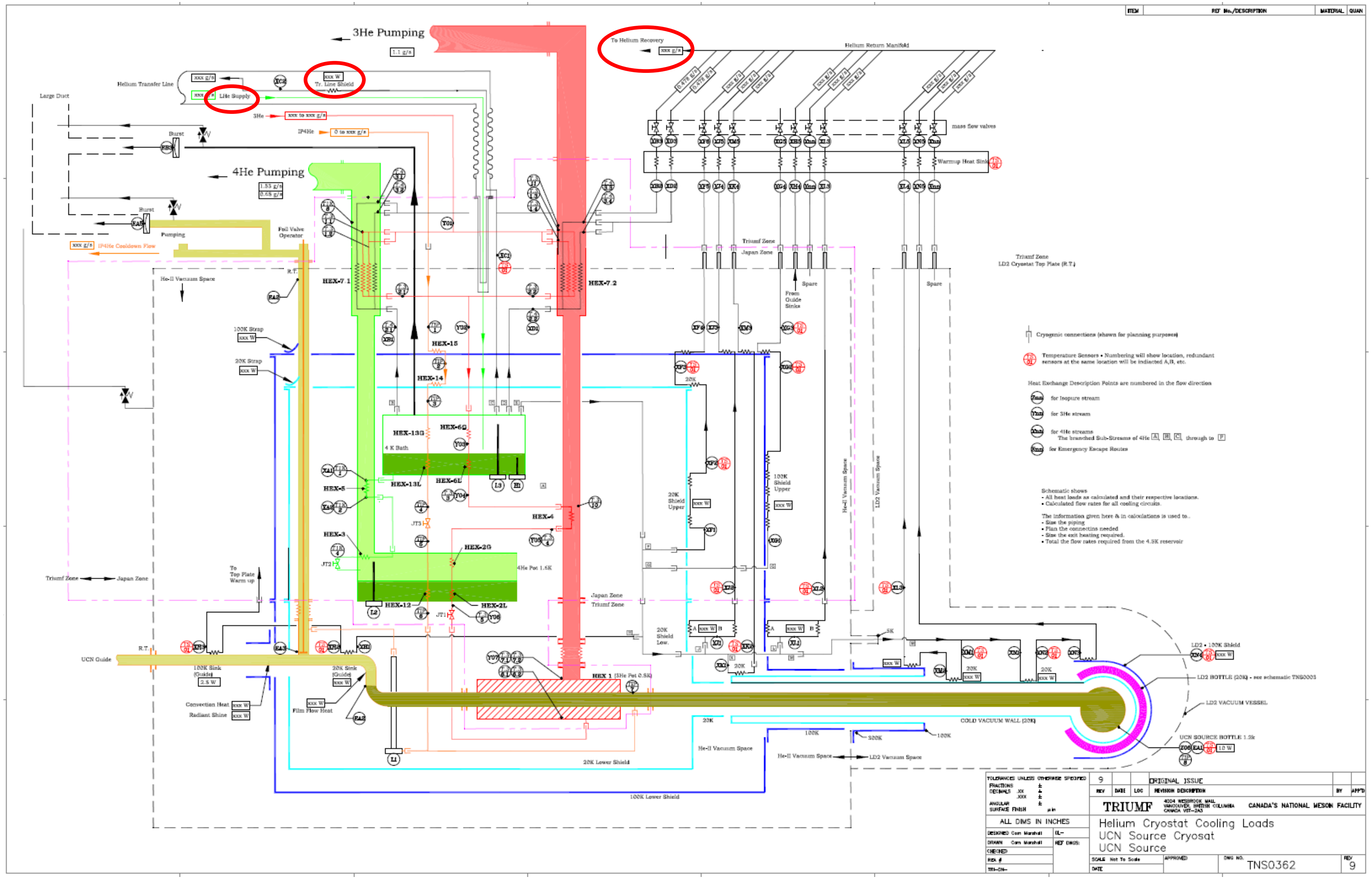
TRIUMF He-II System Schematic



TRIUMF Schematic – Heat Flows (showing 4k boil-off cooling shield flows)



Additional Source for Assumptions Behind Analysis

September 2019 Flow Calculations from Shinsuke Kawasaki:

https://ucn.triumf.ca/meetings-and-workshops/weekly-canadian-group-meetings/new-ucn-source-meetings/2019/2019-08-20/kawasaki_20190820.pdf/view

Conceptual Design Report for the Neutron Electric Dipole Moment Experiment at TRIUMF:

https://ucn.triumf.ca/meetings-and-workshops/review-meetings/2020-02-eac-review-meeting/documentation-for-eac-review/nEDM_spectrometer_CDRDec19-2019.pdf/view

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Thank you
Merci

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