Retention of Molten Salt Reactor Off-Gas

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Workshop on Sources of Man-made Isotope Production
December 2023
WOSMIP Santiago, Chile

Generation IV Reactor Design Groups

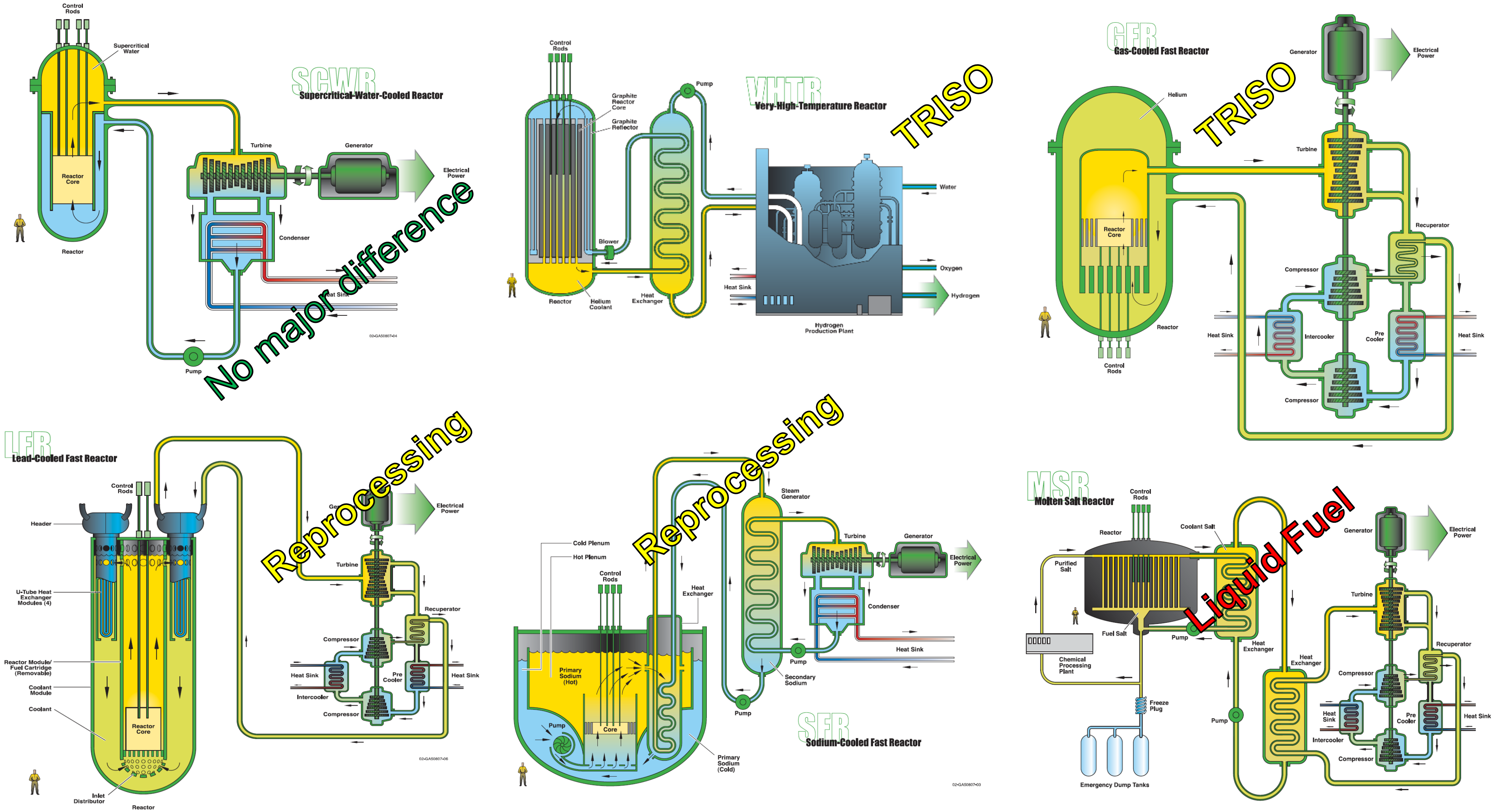
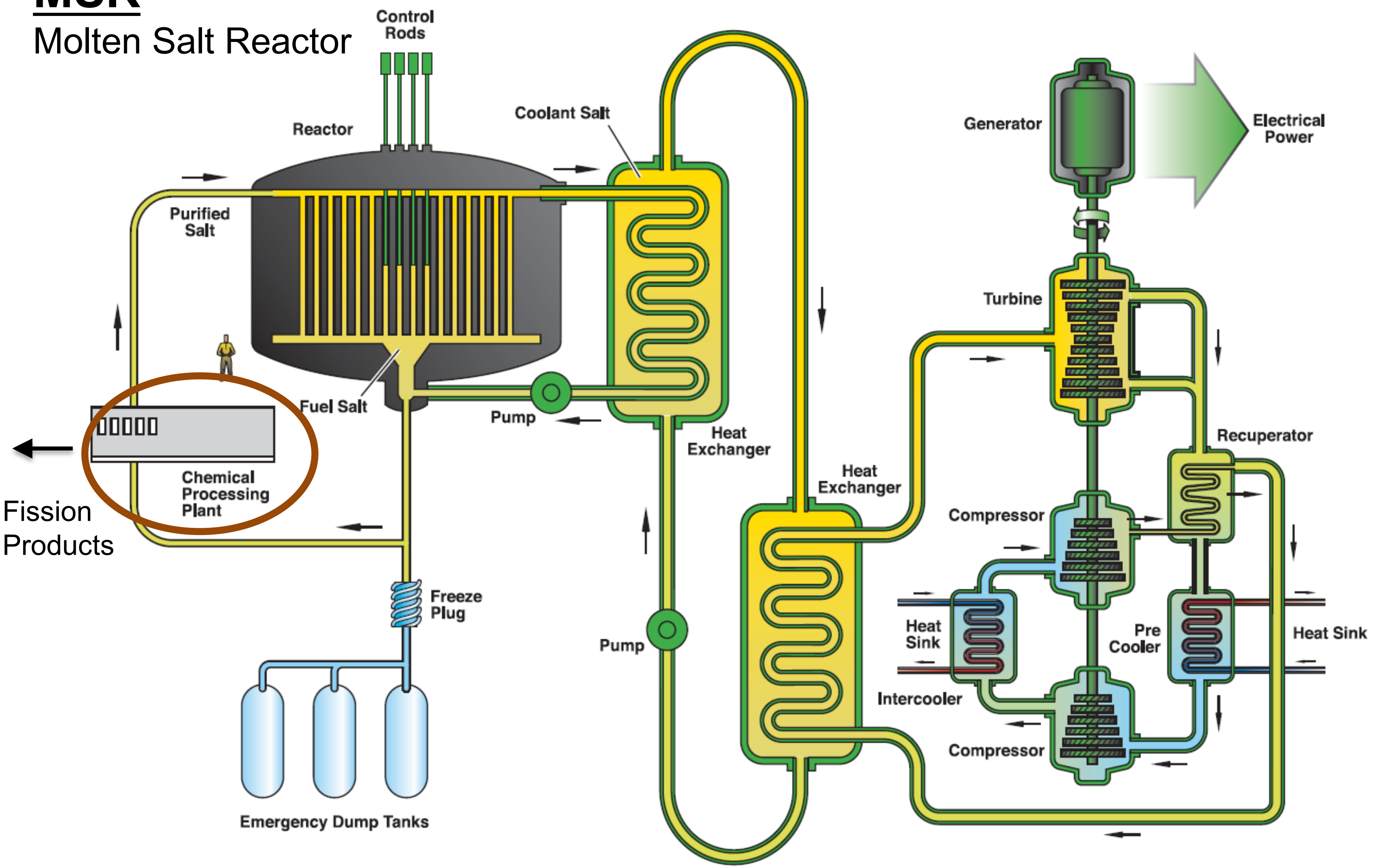


Image Credit:

A Technology Roadmap for Generation IV Nuclear Energy Systems. Issued by the US DOE Nuclear Energy Advisory Committee and the Generation IV International Forum. (Dec 2002)

MSR

Molten Salt Reactor



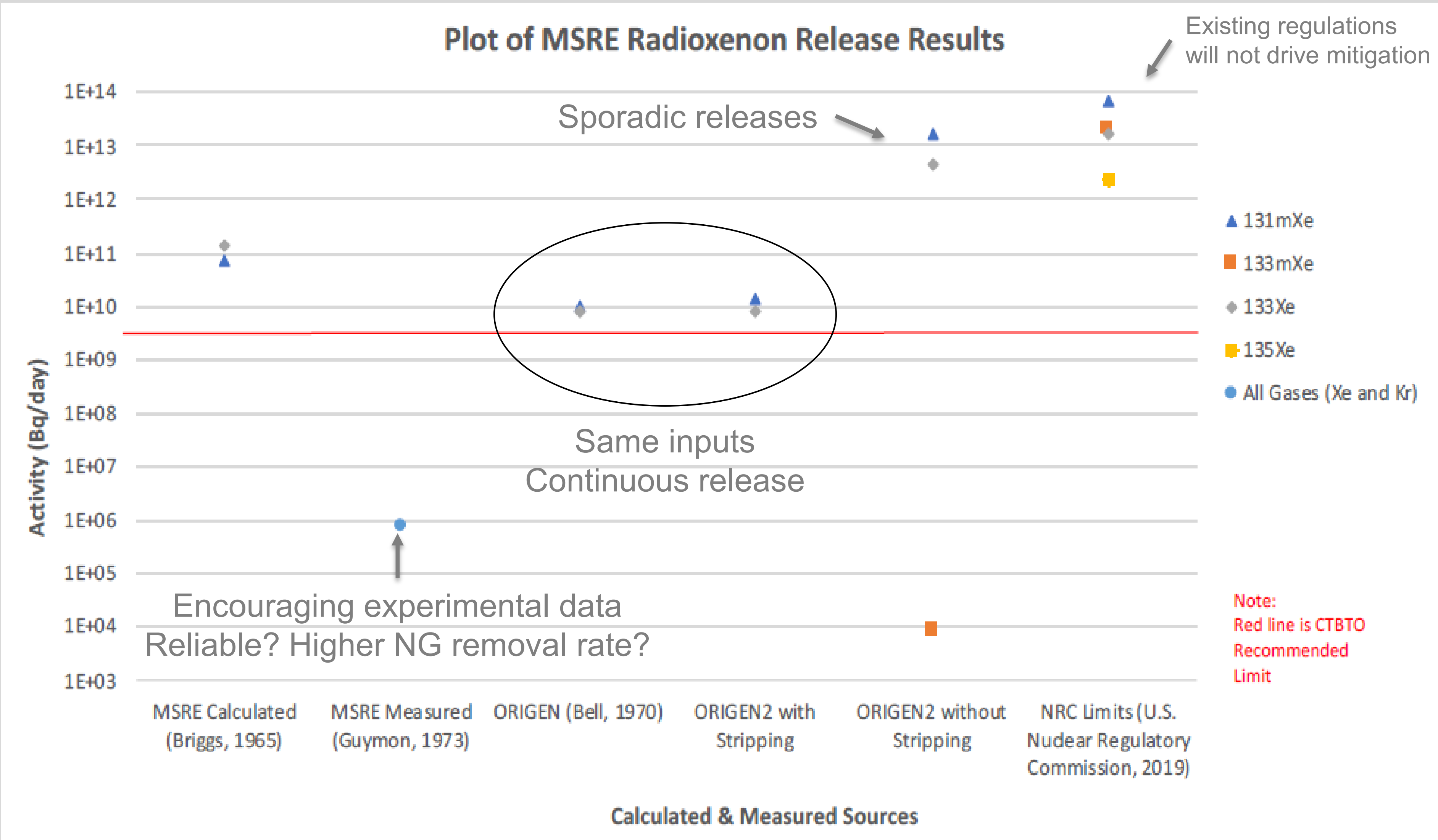
$$P = \frac{E}{t} \qquad 100\ \text{MW} = 6.2 \times 10^{20}\,\frac{MeV}{s} = 2.7 \times 10^{23}\,\frac{fissions}{d}$$

Assume Cumulative Fission Yield for Xe-133 = 5%

$$2.7 \times 10^{23}\,\frac{fissions}{d} = 1.3 \times 10^{22}\,\frac{atoms}{d} = \boxed{2.2 \times 10^{16}\,\frac{Bq}{d}}$$

per 100 MW

<u>Emissions could be 10^{-6}-100% of inventory depending on retention tech</u>


Plot of MSRE Radioxenon Release Results
Existing regulations will not drive mitigation
Sporadic releases
Same inputs
Continuous release
Encouraging experimental data
Reliable? Higher NG removal rate?
Activity (Bq/day)
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
Red line is CTBTO Recommended Limit

Identification of Potential Waste Processing and Waste Form Options for Molten Salt Reactors

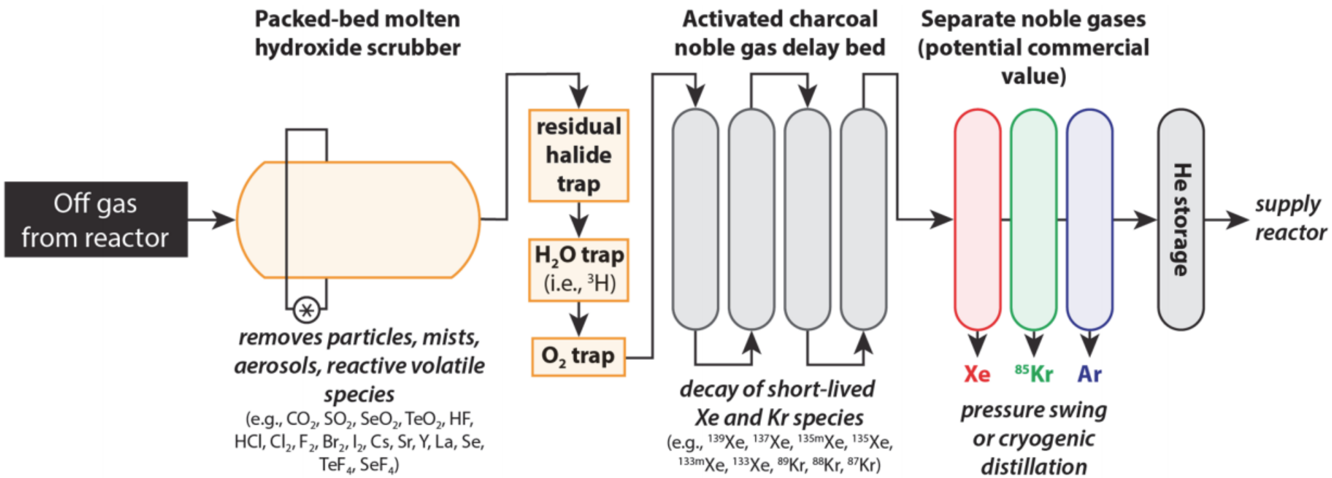


Figure 3-5. Schematic of the overall off-gas system for a commercial MSR based on the MSRE experience. All of the components shown, except the molten hydroxide packed-bed scrubber, are commercially available.

Prepared for
U.S. Department of Energy
MSR Campaign
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[a]Pacific Northwest National Laboratory
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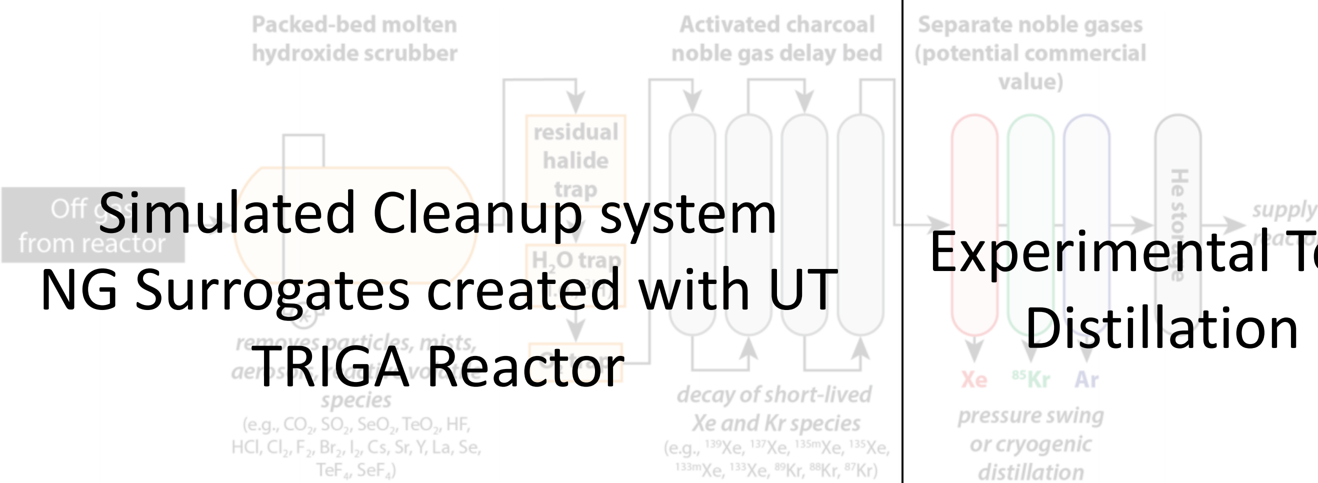
August 15, 2018
NTRD-MSR-2018-000379, PNNL-27723

Identification of Potential Waste Processing and Waste Form Options for Molten Salt Reactors

Simulated Cleanup system
NG Surrogates created with UT TRIGA Reactor

Experimental Testing of Cryogenic Distillation using Liquid He



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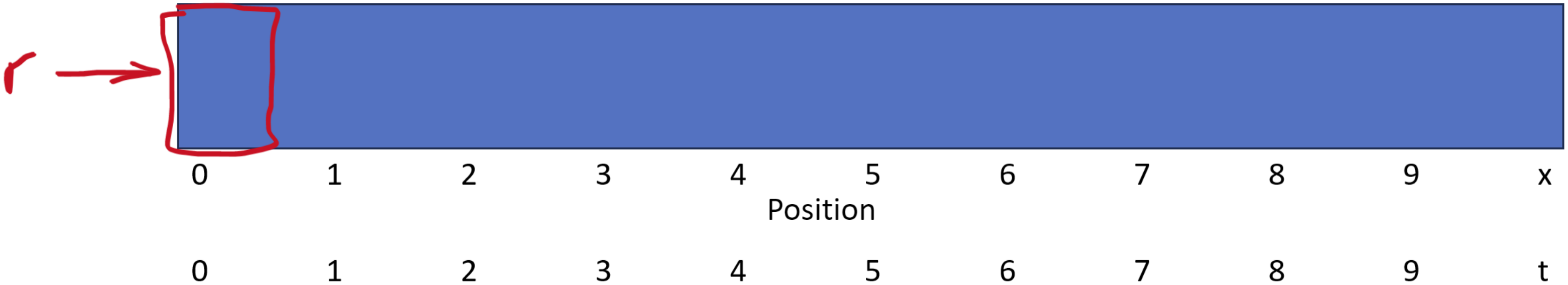
Calculation of NG Concentration



time

Only applies to X=0: Inflow + N(x=0, j-1)*(1-B)*decay + P(i,j-1)*(1-B)*decay

Remaining from same segment of trap

Ingrowth from parent in same segment

Kr-83 atoms in (t,x)
(t=0, x=0) (t=1, x=0) (t=2, x=0) (t=3, x=0)
(t=0, x=1) (t=1, x=1) (t=2, x=1) (t=3, x=1)
(t=0, x=2) (t=1, x=2) (t=2, x=2) (t=3, x=2)

← One of these matrices for each nuclide (including metastable)

All cells not x=0: N(i-1,j-1)*B* decay + N(i,j-1)*(1-B)*decay + P(i,j-1)*(1-B)*decay + P(i-1,j-1)*(B)*decay

Inflow from prior segment of trap

Remaining from same segment of trap

Ingrowth from parent in same segment

Ingrowth from parent in prior segment

B=breakthrough % is a function of element

Calculation of NG Concentration

Position

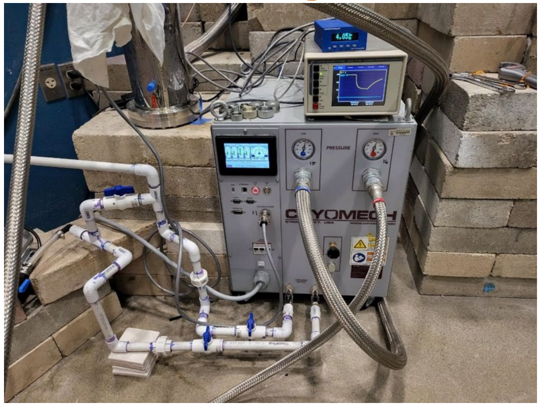
Time

	1	2	3	4
0	0	0	0	0
1	A. 50	0	0	0
2	D. 75	B. 25	0	0
3	F. 87.5	E. 50	C. 12.5	0

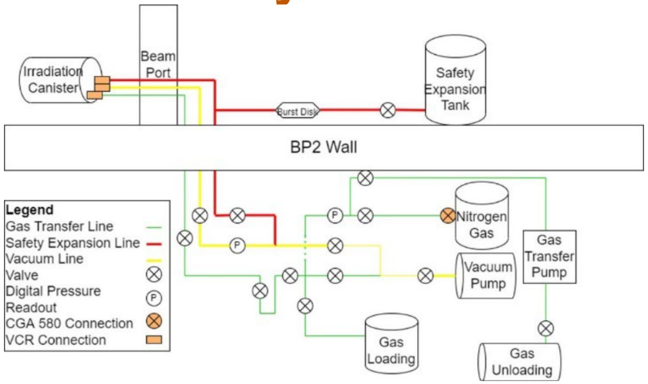
Values are placeholders for creating solving order only. It is assumed ½ of inventory is retained, other half is transferred to next compartment. Letters proceeding atom counts (I.e. A. 50 and B. 25) indicate the order of solving.

UT Cryogenic Irradiation System Overview

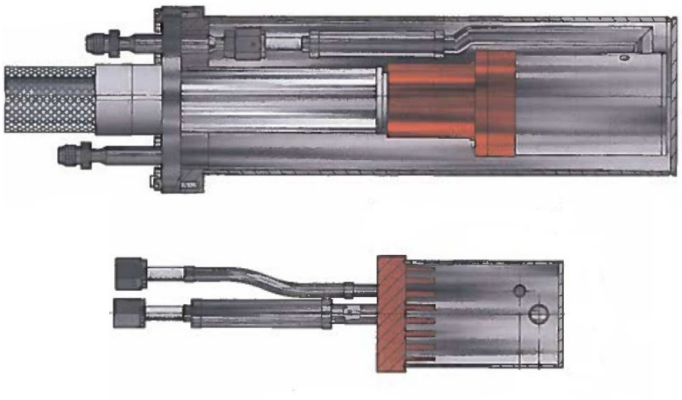
Heat Exchanger



Gas Transfer System

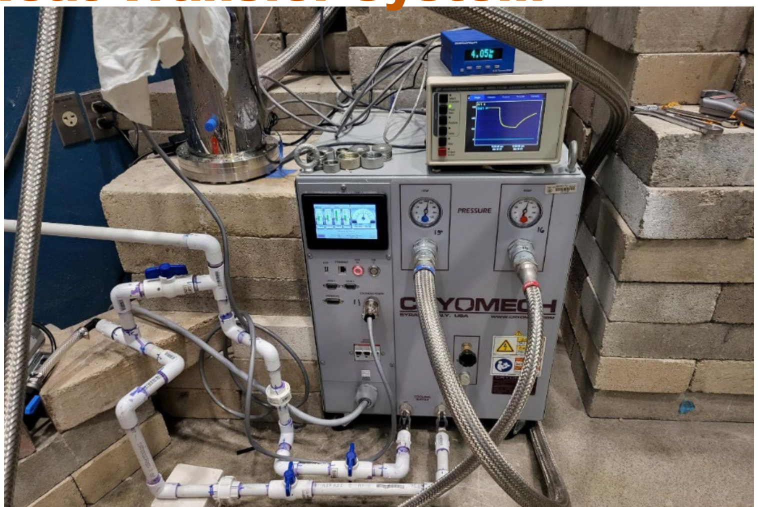


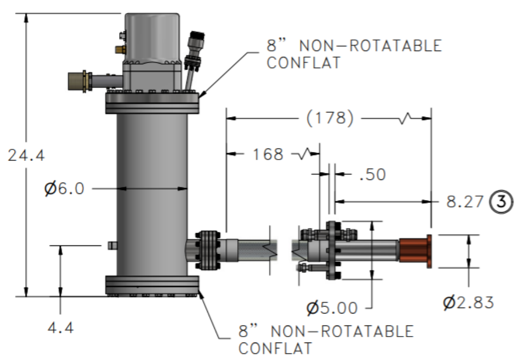
Irradiation Cannister

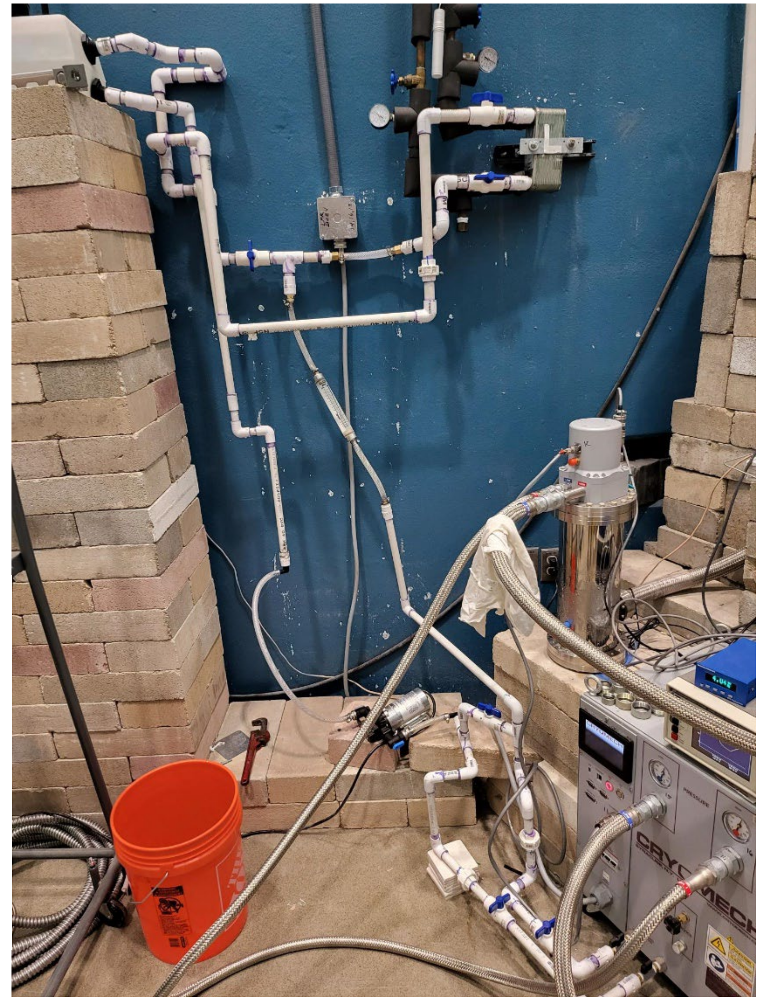


Gas Unloading System

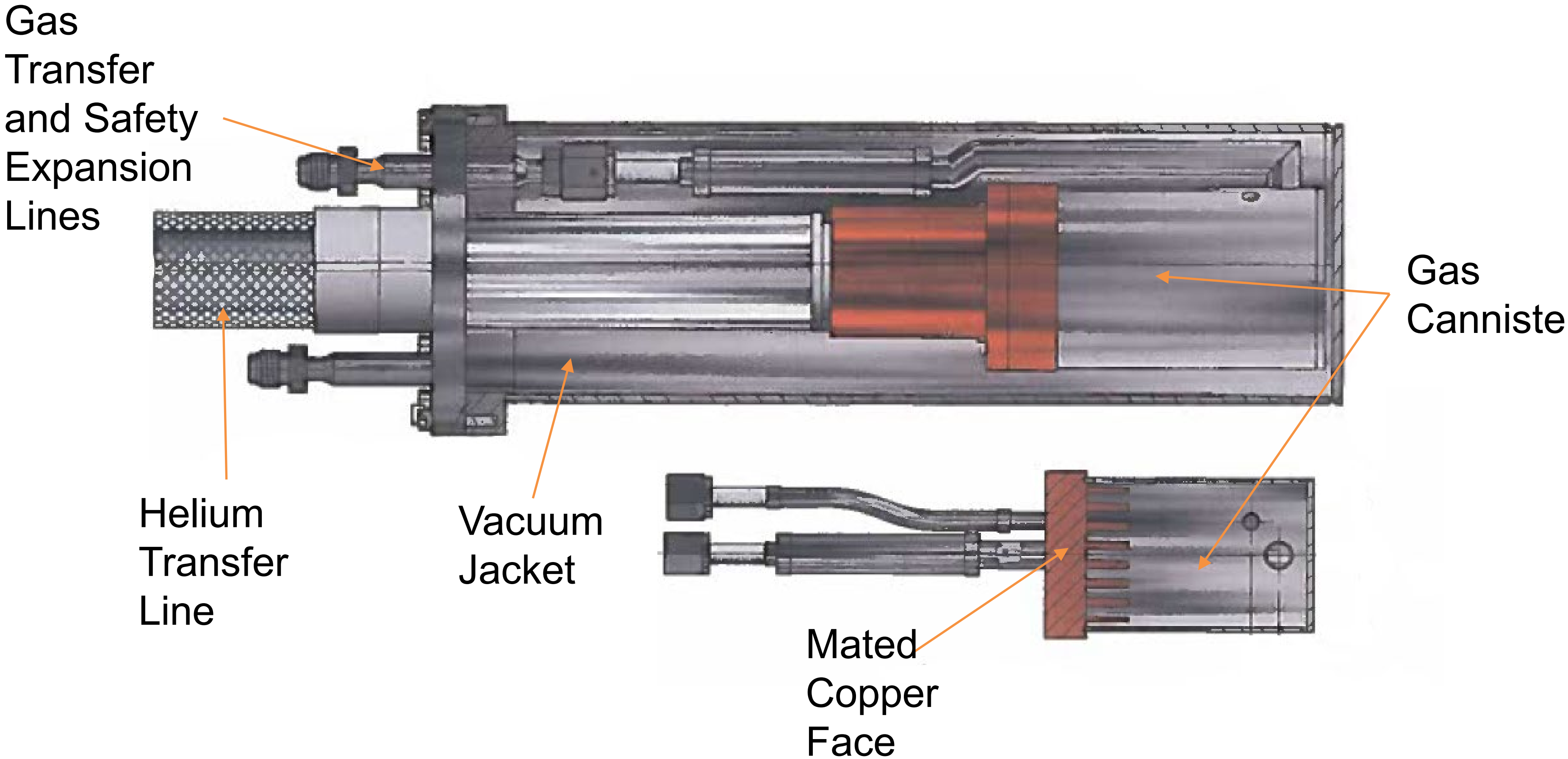
Heat Transfer System



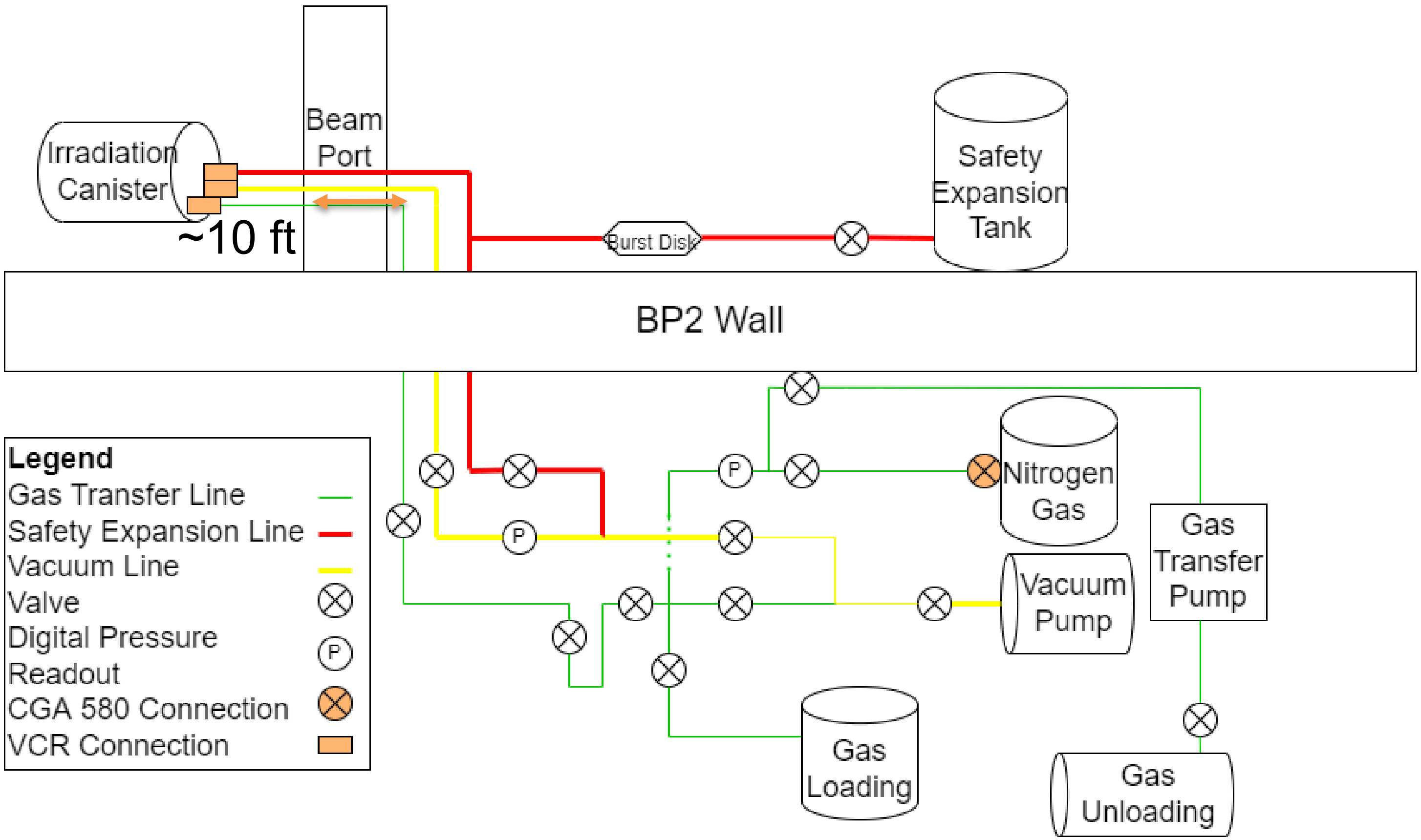




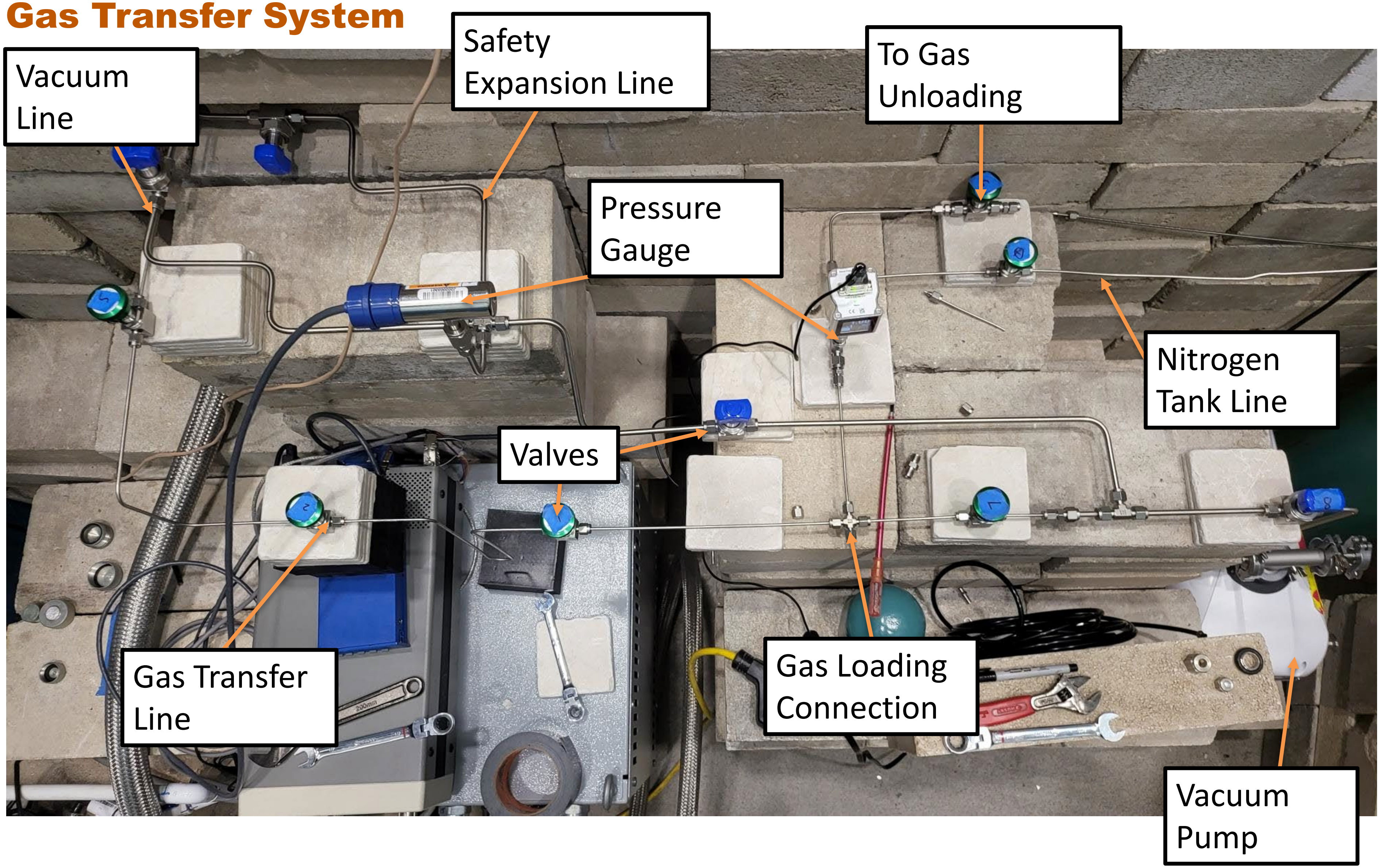
Irradiation Cannister



Gas Transfer System

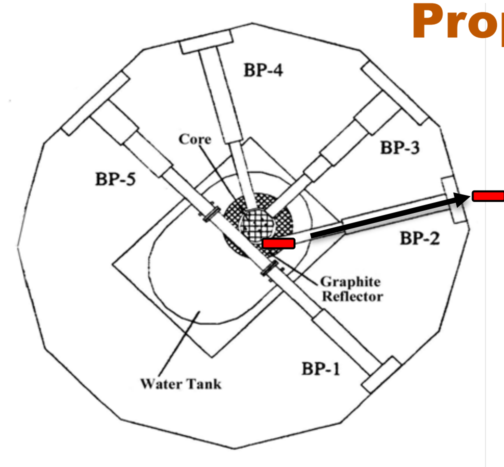


Gas Transfer System

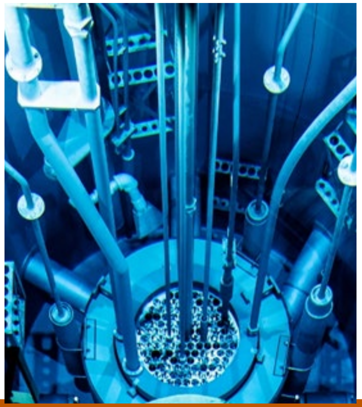


Beam Port Shielding

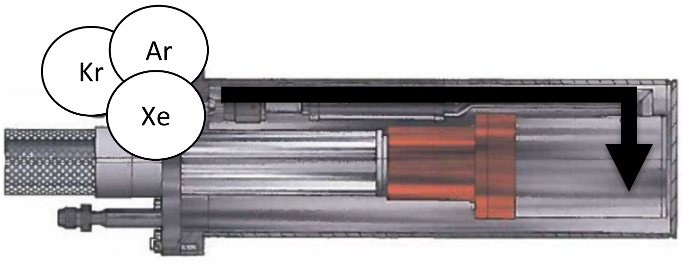
Proposed Changes and Experiment Plan



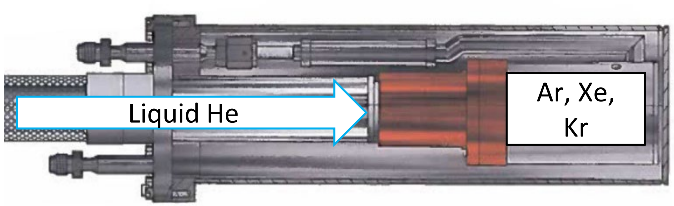
Remove gas canister from beam port



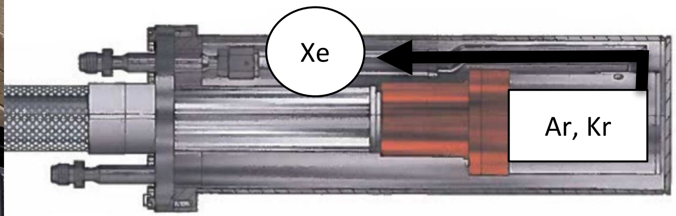
Produce activated noble gases using UT's TRIGA reactor



Load noble gas mixture into gas cannister via gas transfer system, passes through charcoal trap



Utilize helium compressor to freeze gases



Utilize temperature controller to separate and capture individual gases

Measure activities of captured gases

Planned Noble Gases for Experiment

Ar-41

- $T_{1/2}$= 109.61 min
- Relatively inexpensive
- Proof of concept
- Easily accessible

Kr-87/88

- $T_{1/2}$= 76.3 min/2.85 hrs
- Moderately expensive
- Produced during MSRR operation

Xe-135

- $T_{1/2}$= 9.14 hrs
- Third option for completeness' sake
- Expensive
- Produced during MSRR operation

Goals of the experiment

- Repurpose cryogenic irradiation facility to MSRR off-gas retention test
- Separate and capture noble gas mixture, verifying quantity captured via activity measurement
- Demonstrate the efficacy of cryogenic distillation for off-gas retention in the MSRR

Potential Future Deployment at MSRR

Following proof of concept, deployment of a full cryogenic distillation system at MSRR by 2026

Collect off-gases created during MSRR operation for other uses