

HIGH-PRESSURE XENON TRANSFER AND RECOVERY SYSTEM

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Objectives

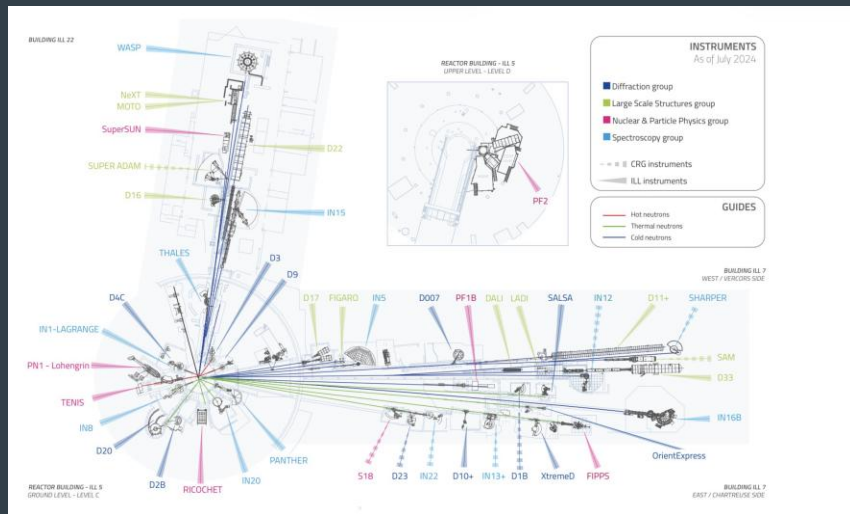
- Discuss the motivation behind the system
- Discuss the vessel and design constraints
- Discuss the transfer manifold
- Discuss some experimental results
- Discuss future iterations and uses

Challenge and Design Principal

- Noble gasses play an important role in nuclear applications
- Gaseous isotopes have low density at ambient conditions (xe-134 = 0.1 g/in³, which limits neutron interaction probability)
- Liquefaction/solidification through cryogenic process introduces experimental complexity and constraints
- The system enables transfer of the isotope into a smaller vessel through cryogenic condensation

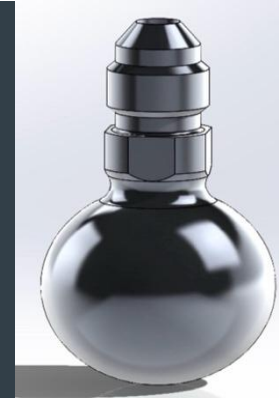
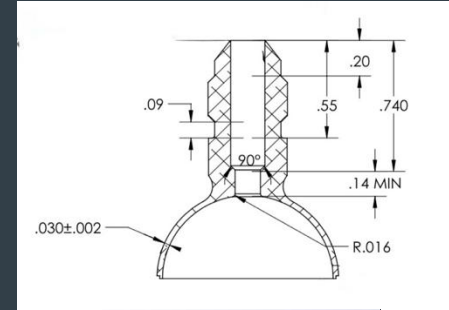
Institut Laue-Langevin, Grenoble, France

- 5×10^7 n/cm²-s at detector at 58 MW
- 3 cycles per year, ~ 50 days per cycle
- Fission Product Prompt γ -ray Spectrometer (FIPPS), 8 HPGe detectors
- Neutron beam diameter of 1.5 cm, with vacuum chamber diameter of 6 cm



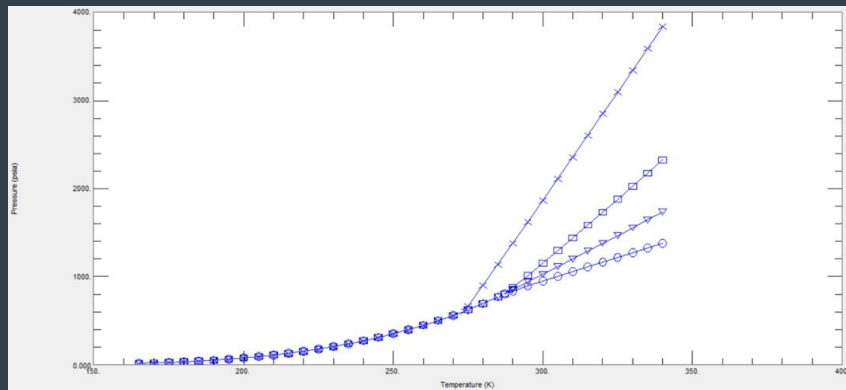
High Pressure Sphere Geometry

- The wall thickness of 0.030 inches provides structural integrity while maximizing neutron transparency, and maximizing the xenon target volume
- The inner volume results in 0.435 cubic inches with an overall length of 1.830 inches
- The neck of the sphere is designed to fit a 1/4" NPT ferrule fitting



Xenon Thermal Modeling

- NIST REFPROP was used along with the Van der Waals equation for a more realistic representation of fluid behavior
- $\left(P + \frac{a}{V^2}\right)(V - b) = RT$
- Using a 5g at STP of Xe-134 into the sphere volume at ~300K, results in approximately 60 bar ~(870 psig)
- The figure shows multiple phases and densities of xenon based on amount filled.
- The bottom line shows 5 grams of xenon in the vessel, at 12.44 g/in³

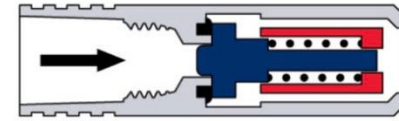


Material Neutron Transparency

- An important aspect of the vessel alloy is neutron transparency
- The 2 main alloys that were discussed were Al 2219 and Al 6061
- 2219 has a higher cross section (0.33b compared to 6061 0.22b)
- 2219 showed better better machinability and welding results and similar structural strength
- SS 316 and titanium result in substantial neutron absorption
- Pure aluminum has low neutron absorption but lacks the required strength

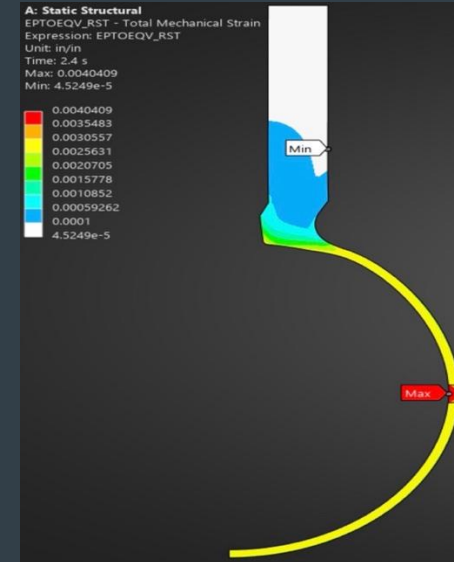
Lee Check Valve

- The vessel needed to maintain containment of the gas without external components
- A Lee check valve was used to ensure the sphere would remain pressurized
- When ready to evacuate, a specialized tool is used to open the check valve, and allow depressurization of the sphere



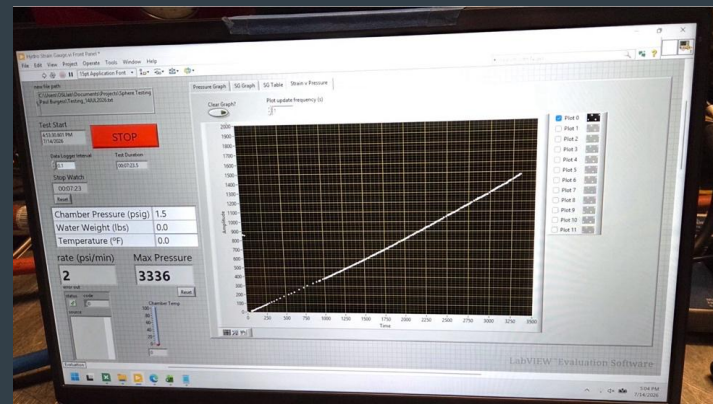
Finite Element Analysis

- Initial FEA shows nearly uniform stress through the body
- Analysis of the EBW shows nearly uniform stress along the equator
- Predicted strain well below allowable limits of intended operating pressure of 60 bar
- Expected burst pressure of 200 bar (~2900 psig)



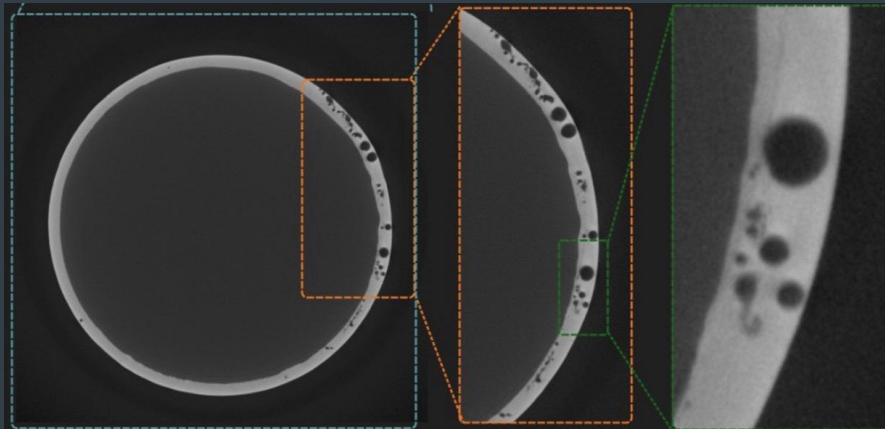
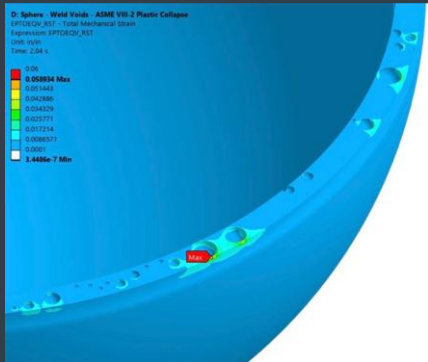
Hydrostatic Test

- A hydrostatic test was performed on the sphere
- Using water as the test medium at a rate of 2 psi/min
- The sphere ruptured at 3336 PSIA (230 bar), almost 4 times the intended operating pressure, and 300 PSIA more than what was predicted by initial FEA
- The rupture happened at the seam of the weld, where expected



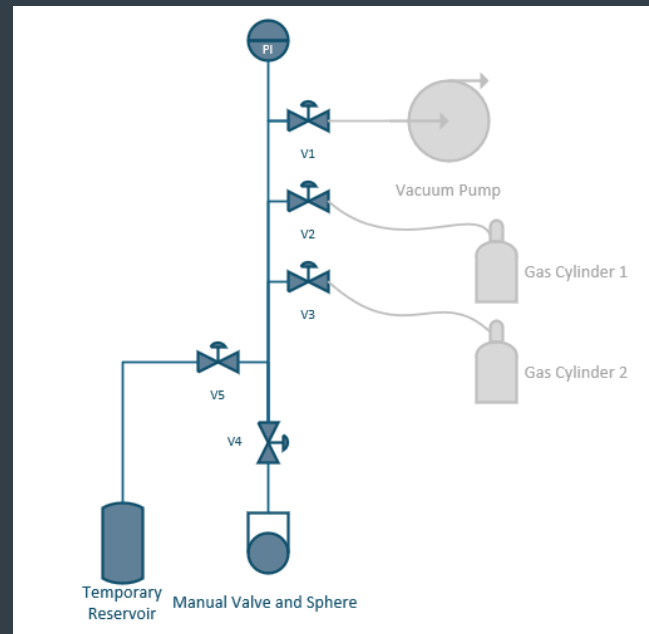
Radiography

- Performed at ILL, revealed small spherical voids in vicinity of weld
- FEA revealed a nearly uniform stress distribution, despite the voids
- Very small areas of highly localized stress were seen adjacent to the voids, but had little influence in overall deformation of the sphere
- Final FEA lowered the predicted burst pressure by 15% to 170 bar, but still close to 3 times the intended operating pressure of 60 bar

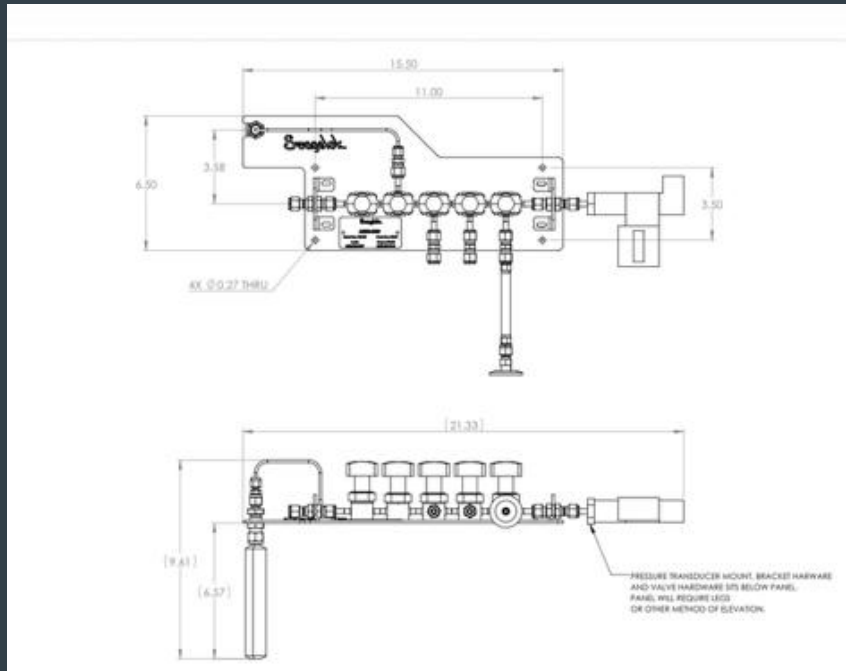


Gas Manifold

- Design required connections for pressure monitoring, vacuum pump, multiple gas cylinders, the sphere, and a reservoir
- Provides a means for transferring, storing, and evacuating multiple gasses through multiple vessels
- A pressure transducer in the main line allows continuous monitoring while using the system



Pressure integrity and dead volume



- Composed of commercially available components all provided from Swagelok.
- Orbital welding was used on all manifold piping and valves
- Stainless-steel 316 was used for its excellent resistance to corrosion, strength, and compatibility with gaseous isotopes.
- Compression style fittings were used for all external connecting points to provide reliable sealing under repeated pressure and thermal cycling.

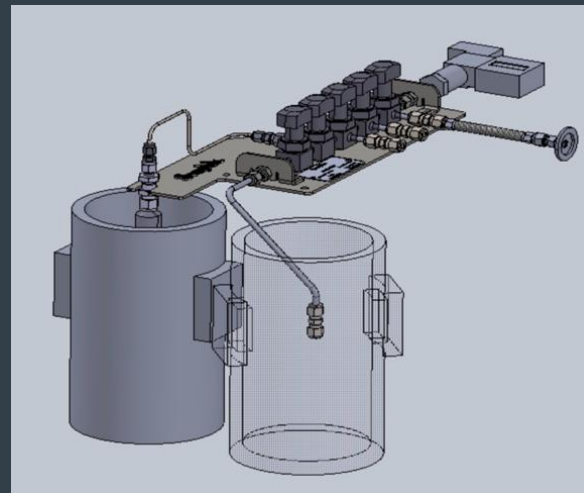
Temporary Reservoir

- A reservoir was added to increase flexibility during transfer and recovery using multiple gasses
- The volume simplifies handling while reducing steps needed during routine operations
- The reservoir also serves as a pressure buffer during cryogenic transfer, moderating pressure transients



Cryogenic Condensation Transfer

- The transfer and recovery of xenon is facilitated through the use of liquid nitrogen,
- The receiving vessel is immersed in liquid nitrogen, reducing the temperature to $\sim 77\text{K}$
- This temperature increases the vacuum in the vessel, and condenses the xenon as it enters
- When the transfer is finished, the dewar is removed, and the vessel is allowed to return to room temperature
- Eliminates moving components like pumps, provides excellent reliability with repeated filling cycles

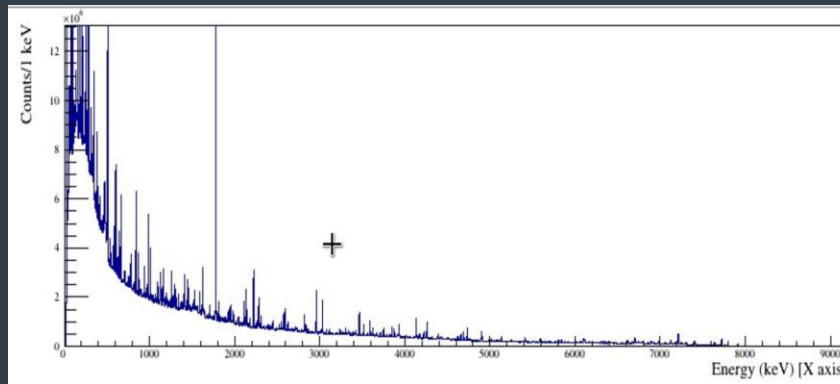


Experimental Results Xe-134(n, γ)Xe-135

- With about 2.4 grams of Xe-134 in the sphere, the sample has been irradiated at ILL since 9/5
- The corresponding spectrum is being analyzed for both existing and new data
- NNDC data is supported up to ~3200 keV, while the spectrum shown could contain data out to full recorded separation energy of 6359 keV

References:

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|---|--|---|--------------------------------------|
| A | ^{135}I β^- decay (6.58 H) | B | ^{135}Xe IT decay (15.29 M) |
| C | ^{136}Xe (p, d) | D | ^{136}Xe (d, t) |
| E | ^{208}Pb (^{18}O , F γ) | | |

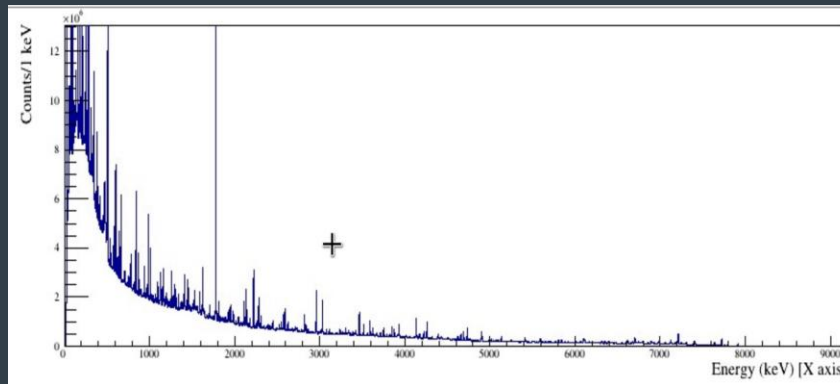


Experimental Results Xe-134(n, γ)Xe-135

- Previous neutron separation energy recorded as 6359 +/- 4 keV
- Data we've measured shows 6351 keV with better than 1 keV precision
- This could affect what we know about current Xe-135 and I-135 data.

References:

- | | | | |
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| E | ^{208}Pb (^{18}O , Fy) | | |



Future Development

- The primary goal for development would be optimizing the irradiation target
- The current vessel is designed well beyond what the intended use is, minimizing material and adjusting the design could help with neutron transparency
- Filling efficiency is less than 50%. Continuous improvement of the filling procedure can allow for higher probability of interactions
- Incorporating neutron transport simulations into the design would identify accurate effects of scattering, absorption, and long term neutron irradiation

Conclusion

- Addresses principal challenges associated with irradiation of noble gasses
- The high integrity transfer system with high strength pressure vessels allow reliable, repeatable processes
- The design establishes a base platform that allows for multiple iterations for future applications
- Today's capability will provide the data needed to improve nuclear data libraries for further use in reactor physics, neutron activation analysis, and many other applications



Thanks

- SwRI for providing not only the design of the sphere, but conducting the FEA and testing needed to ensure safe handling of the isotopes
- Swagelok for providing several designs for the manifold to ensure our needs for the experiment were met
- ILL for allowing beam time to perform the experiment, and performing radiography on the vessels
- Rene Reifath at LANL for providing the initial framework for the transfer system and spherical vessels

Questions