TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics

Reliability Considerations in Underground Isotope Transfer System Design

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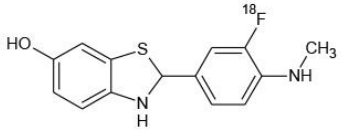
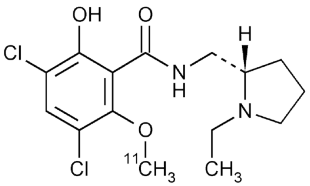
Summary

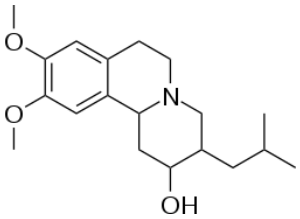
- Project background
- Outline design steps
- When and how do reliability considerations fit into the process?
- Product Development Process
  - Concept
    - Requirements Specification, Conceptual Design
  - Design
    - Detailed Design (mechanical, electrical, controls)
  - Assurance
    - Design Review, FMEA
  - Manufacture
  - Launch
    - Commissioning, training
- Video demonstration

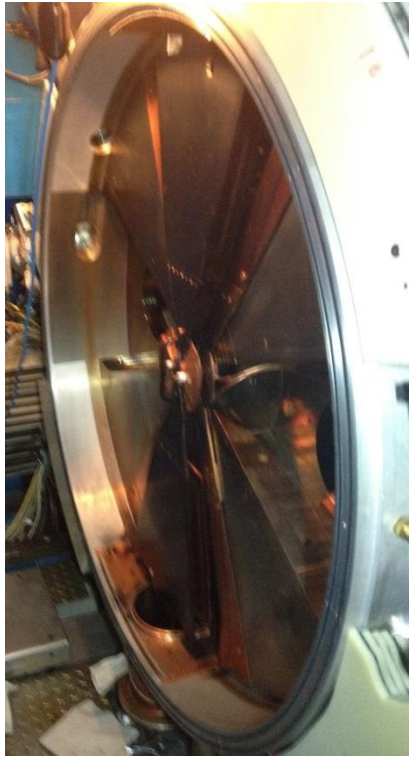
TRIUMF Life Sciences

- 13 MeV cyclotron produces ^{11}C, ^{18}F, ^{64}Cu, ^{67}Ga, and other isotopes
- TRIUMF production chemists make PET isotope (^{11}C, ^{18}F) tracers



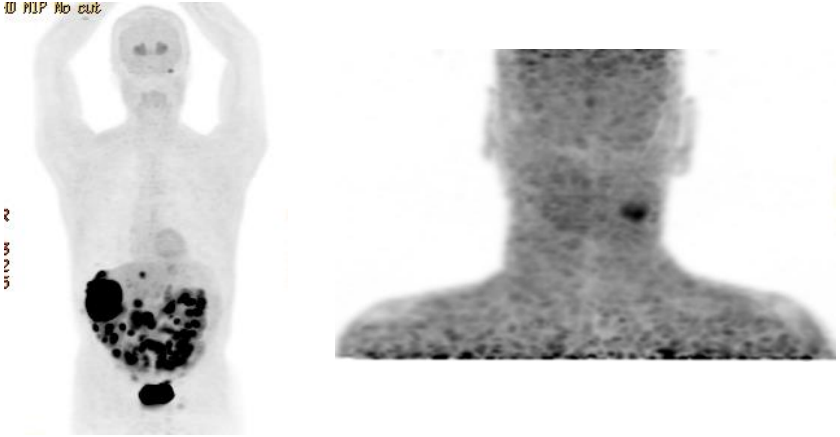


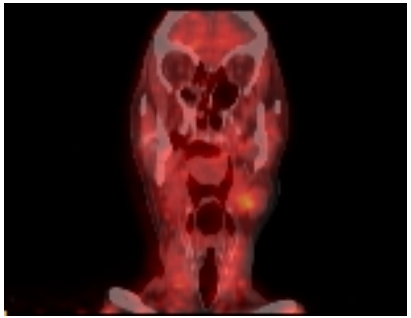


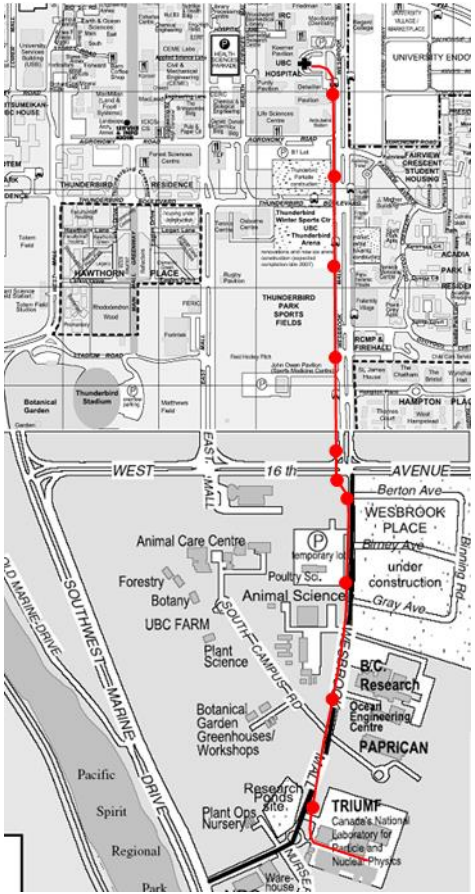


TRIUMF-UBC Collaboration

- PET imaging (Parkinson's, Alzheimer's, etc.) facilities located 2.7 km away from TRIUMF at the UBC hospital
- $t_{1/2}(^{11}C)$ ~ 20 mins., $t_{1/2}(^{18}F)$ ~110 mins.
- Underground pneumatic delivery system
- New pipeline added to second facility in 2015 (~0.5 km away)

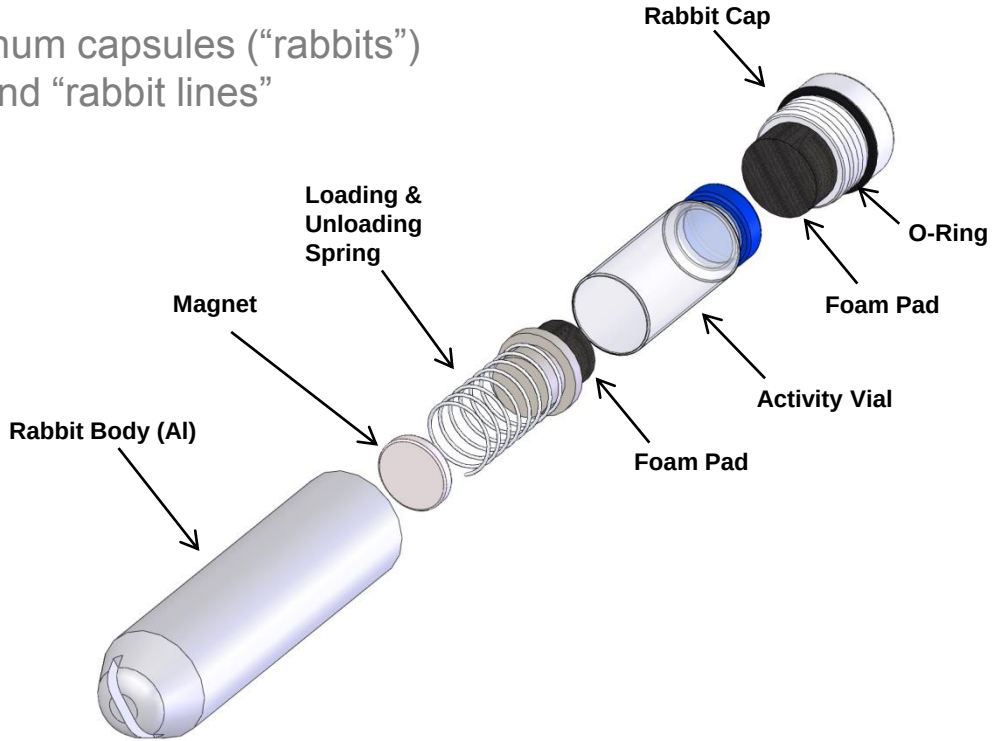






TRIUMF-UBC Deliveries

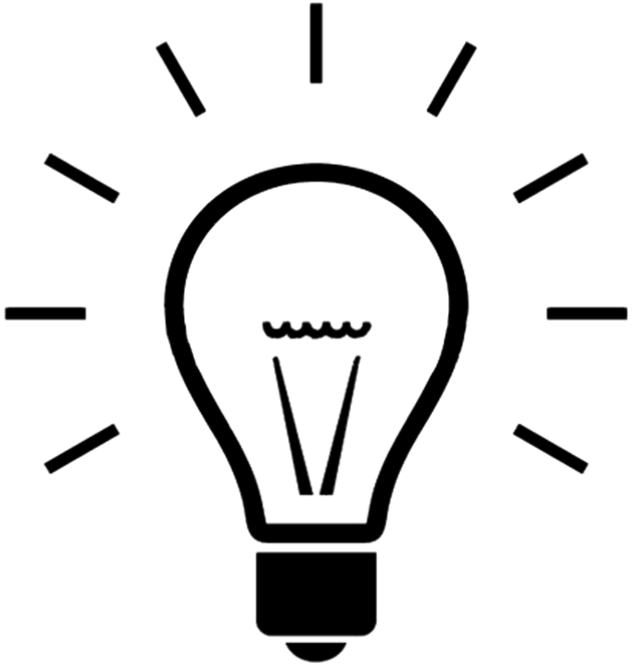
- Tracers made at TRIUMF are secured in aluminum capsules (“rabbits”) and propelled to destination through underground “rabbit lines”



Product Development Process

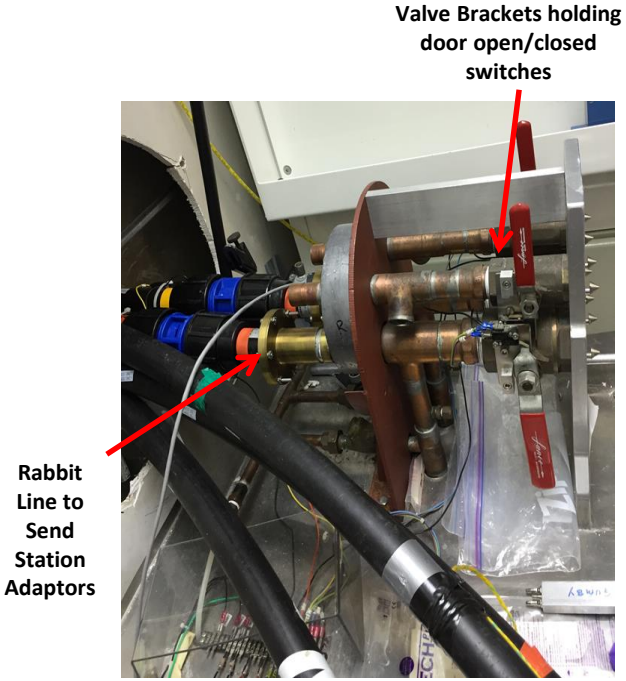
Steps

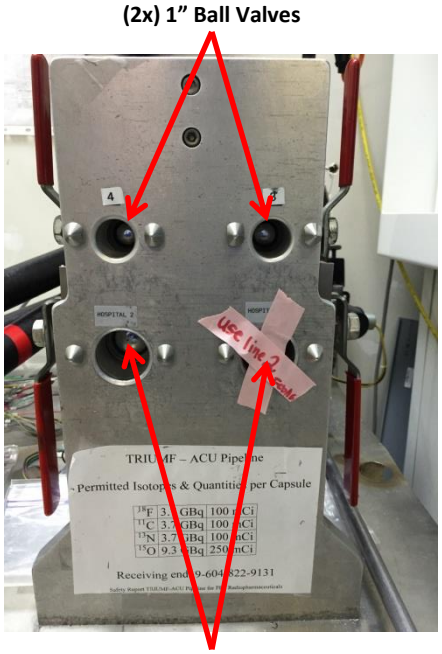
- Concept
- Design
- Assurance
- Manufacture
- Launch

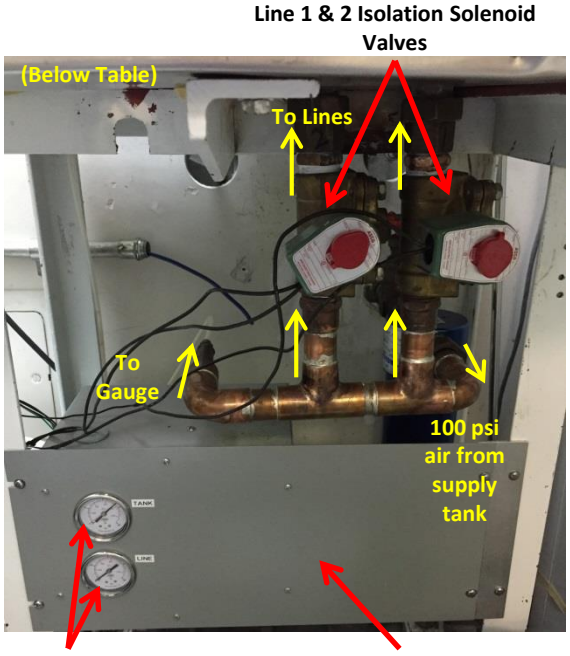


Send Station to be Upgraded

- Send Station is located in a chemistry lab at TRIUMF, providing air propulsion
- Two lines in place connecting TRIUMF to UBC hospital, with entrances for two smaller lines that were never used, must be upgraded to accommodate two new larger lines to CCM







Process

- Analyze design requirements
- Predict operating conditions
- Determine reliability risks
- Develop “Requirement Specifications” document outlining results
- Review and approval of the document by senior engineers and managers
- Develop conceptual outline

Reliability Considerations

- ^{11}C tracer preparation time ~30 mins, optimistic EOB to injection time of 45 mins. (~2.5 half-lives)
- Doses can be very difficult to reschedule
- Consistent, reliable performance necessary to meet time demands
- High pressure air (100 psi) presents risk to chemists
- Rabbits not reaching their destination amount to a radioactive source underground in public
- Multiple deliveries per day for many years

Major risk

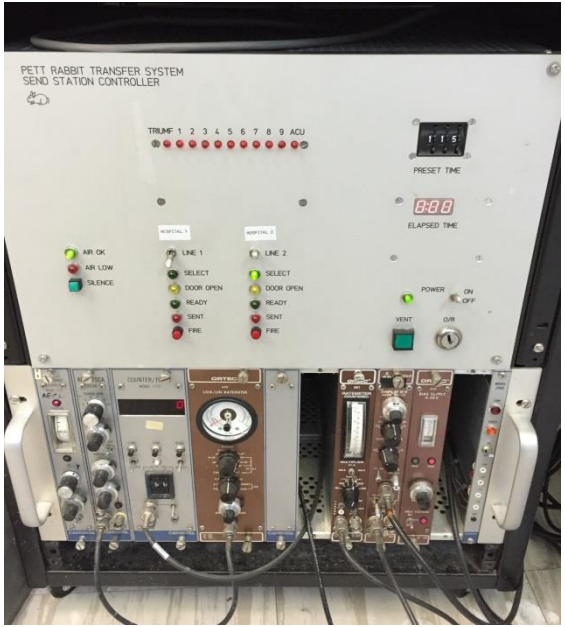
Human Factor: Accidentally sending a rabbit to the wrong destination.

- Mistake could lead to injury or contamination at destination

Potential Solutions:

Rabbit Locators

Receive Station Interlock Button



Send Station Safeguards

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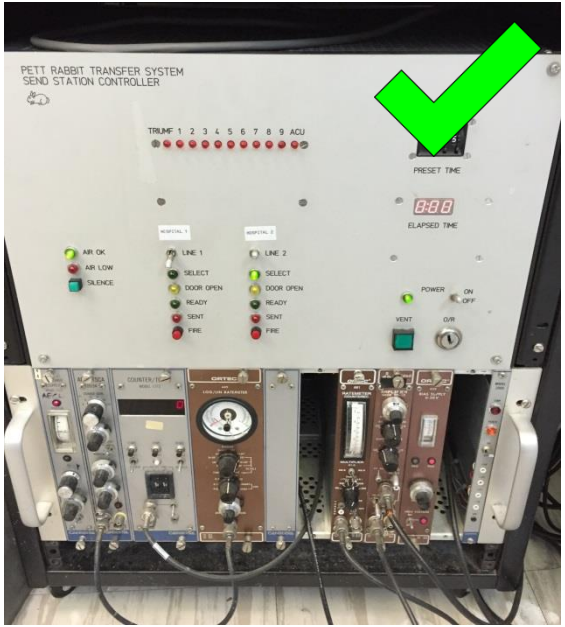


Send Station Safeguards

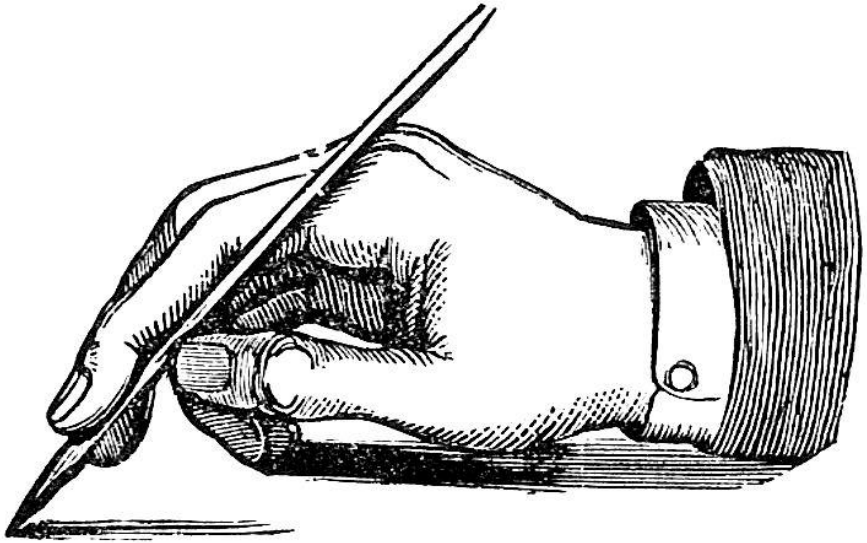
Rabbit Line Concept Results

- 4 rabbit line connections
- Each line isolated from the supply tank by a solenoid valve
- Each line pressure monitored separately
- Send station piping attached to rabbit lines with tight clamps and O-rings
- New PLC CPU, new control code
- PLC Interlocks established
- A touchscreen HMI (Human-Machine Interface) will operate the rabbit line
- This HMI will engage the user and help protect against operator error

Product Development Process

Steps

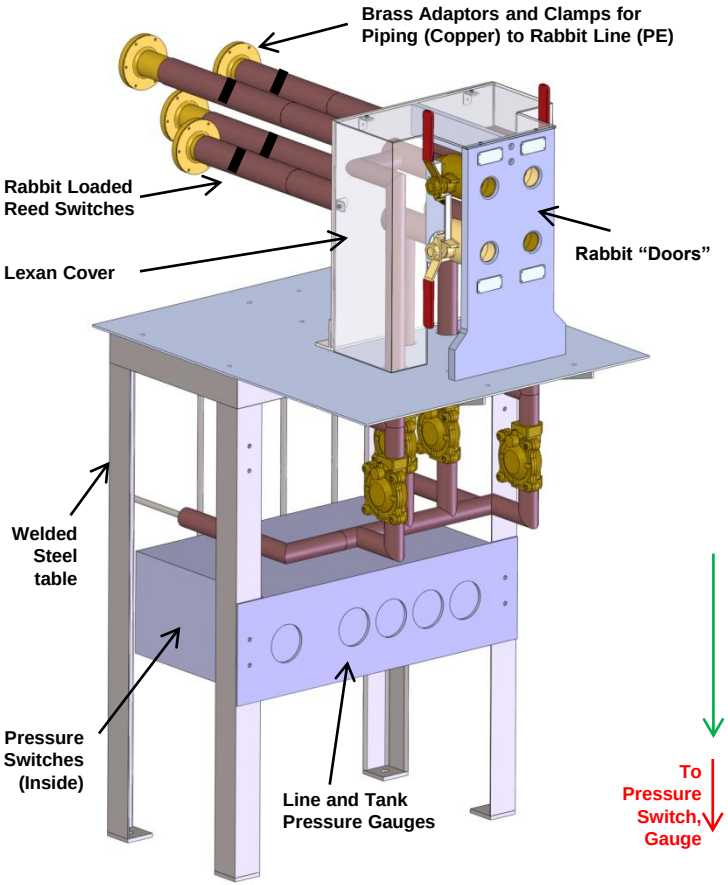
- Concept
- Design
- Assurance
- Manufacture
- Launch

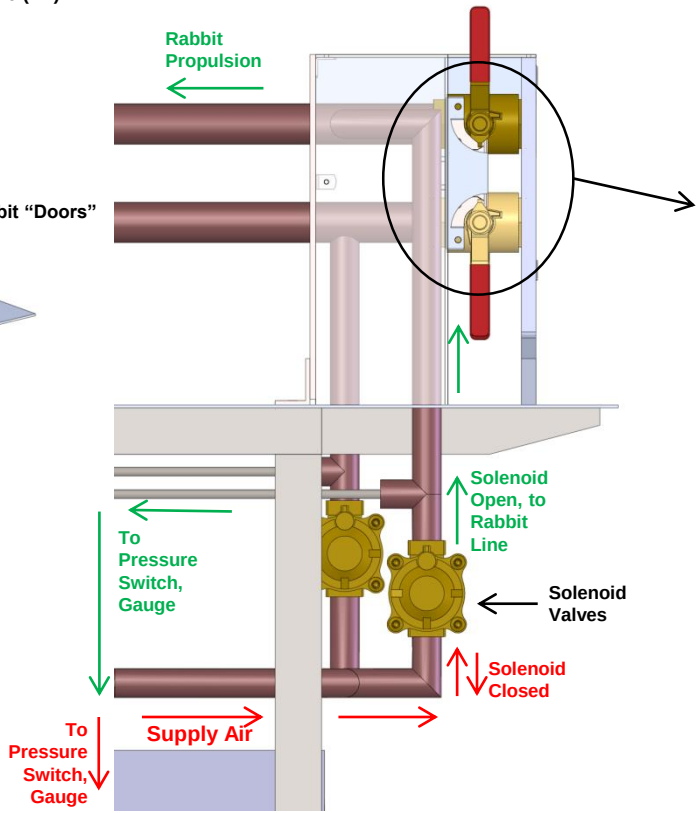


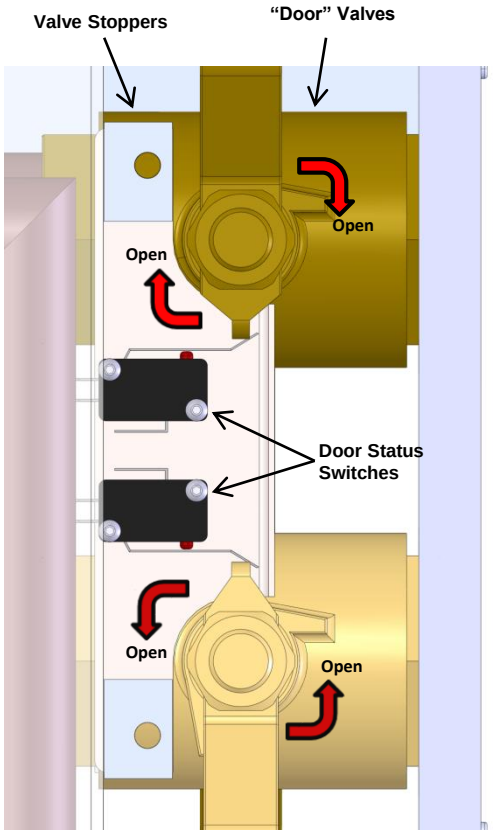
Process & Reliability Considerations

- Proceed to detailed design
- Account for reliability considerations
- 3D model mechanical parts/assembly
- Engineering drawings for parts to be manufactured
- Electrical calculations to determine control device circuitry
- Spec out all electrical/mechanical components
- Write PLC code to control system and implement interlocks
- Simulate PLC code in software environment
- Develop HMI software, simulate

Mechanical Design

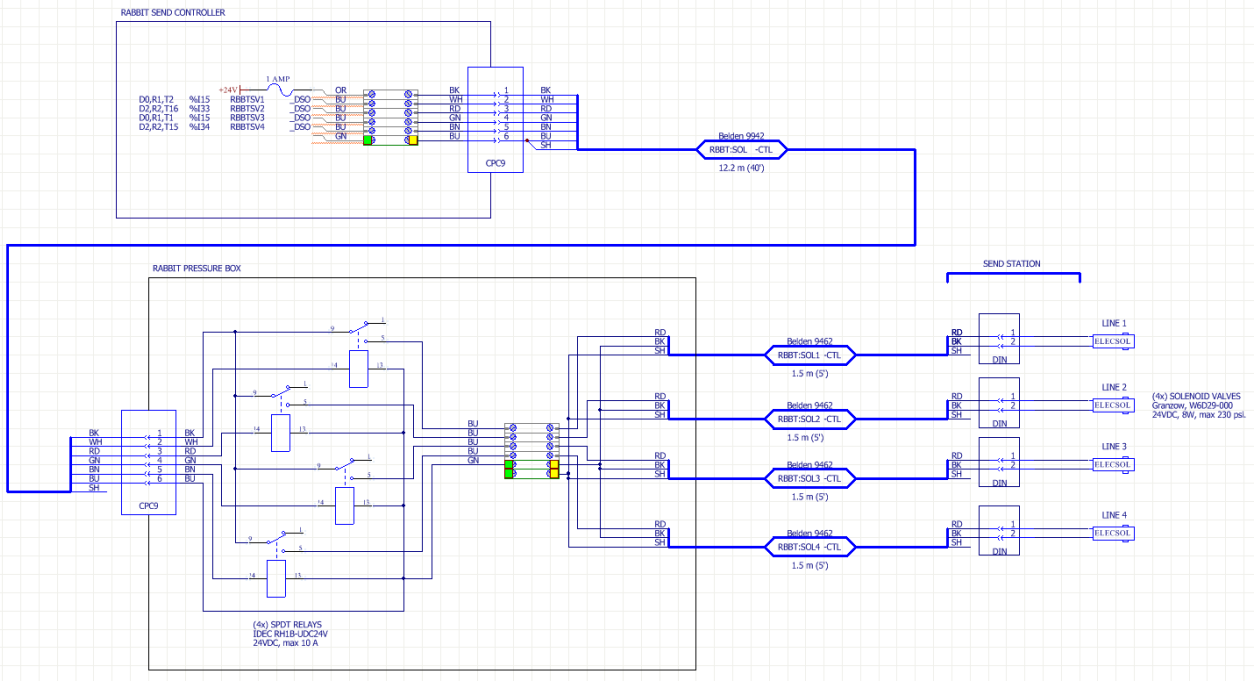




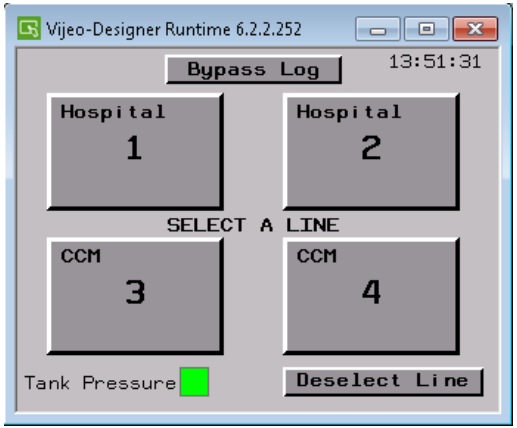


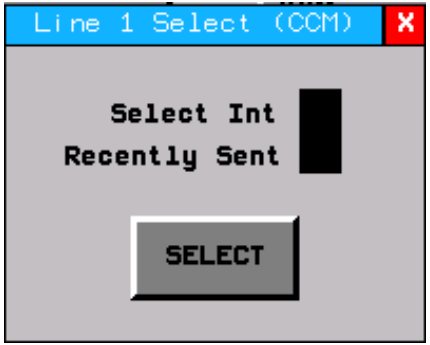
Electrical Design

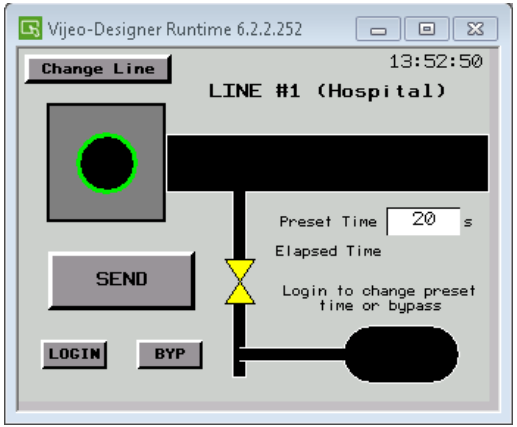
- Calculate appropriate values for circuit components (resistors, etc.)
- Choose components rated for operation well within desired levels to ensure reliability
- Use relays to control solenoid valve power

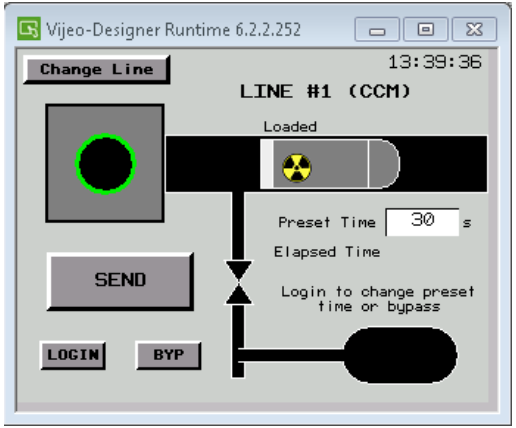


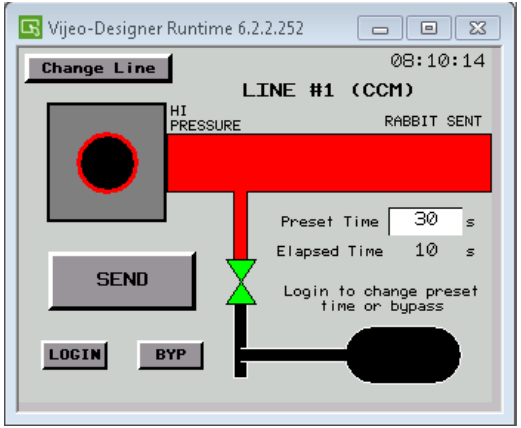
Controls Design (HMI)





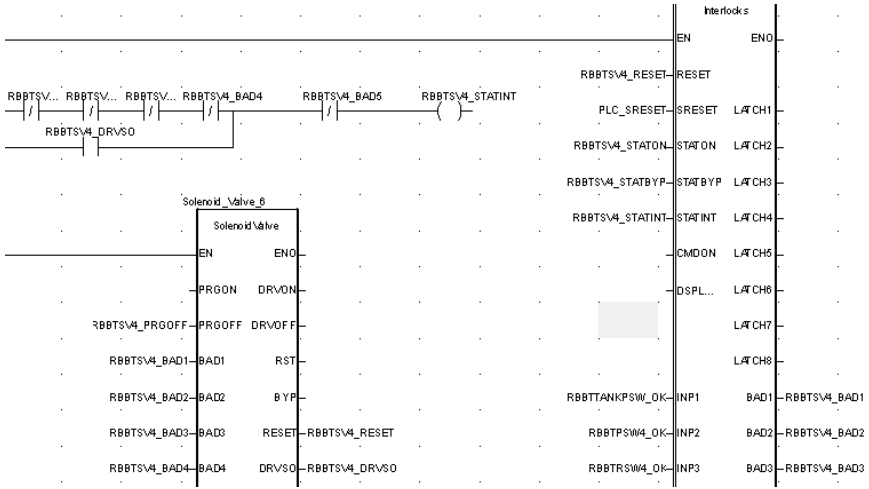






Interlocks to Send a Rabbit

- Line selected on HMI
- Valve “Door” closed
- Rabbit loaded and pushed past reed switch
- Line pressure below 20 psi
- Tank pressure >80 psi
- “SEND” button on HMI → PLC sends solenoid drive signal for a pre-set time
- After time elapses drive signal ceases, interlocks reset
- An interlock bypass can be initiated with a password on the HMI to bypass all interlocks EXCEPT for the door



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Process & Reliability Considerations

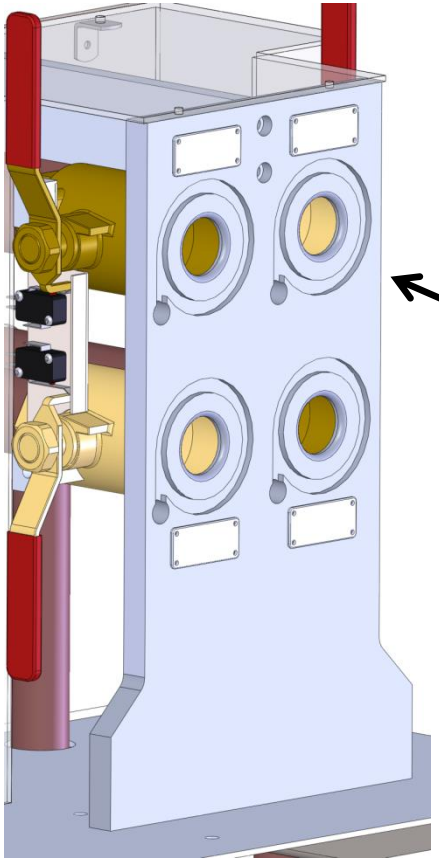
- Perform FMEA (Failure Mode and Effects Analysis)
- Revise design to address significant risks
- Conduct a design review with senior engineers and management
- Analyze the design’s ability to meet pre-determined requirements
- Revise the design once again to address issues determined in design review

Rabbit Send Station FMEA Example

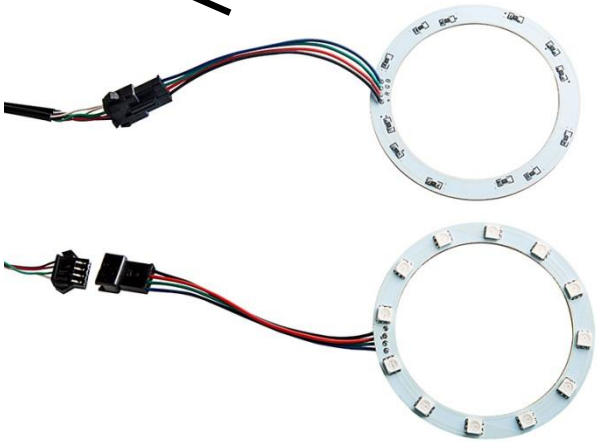
Component, Process, or Step	Potential Failure Mode	Potential Effects	Severity	Potential Causes	Likelihood of Occurrenc	Controls/Mitigation	Undetectability	Risk Priority Number
Send Station	Pipe adaptor/Clamp Failure.	Rabbit line blows off from send station. Operator safety hazard.	9	O-ring failure, plastic rabbit line degredation, strain on adaptor.	2	Test adaptors many times with pressure. Ensure pieces are machined well and soldering is clean. Place HMI away from send station so even with a failure, injury is extremely unlikely.	9	162
Send Station	Rabbit Delivered to wrong facility	Worst Case: Injured Chemist at destination, contamination spread. Best case: lost dose.	8	Operator error, not paying attention to labels and complacency.	8	HMI screen destination labels, destination labels above lines.	7	**448**

- Determined to be insufficient mitigation of accidental delivery risk
- Need a way to more fully engage operator in the sending process, guarding against complacency

Solution



- Integrate ring LEDs into rabbit line entrance design
- RGB lights can also display line conditions with different colours
- Bright visual cues, heightened operator engagement



Colour & Priority Code

Priority	State	LED Colour
1	Line pressurized (Do Not Access)	**RED**
2	Line selected, to be loaded	**GREEN**
3a	Line loaded, solenoid interlocked	**YELLOW**
3b	Tank pressure low (all LEDs)	**YELLOW**
4	Line ready to send rabbit	**GREEN (Flashing)**

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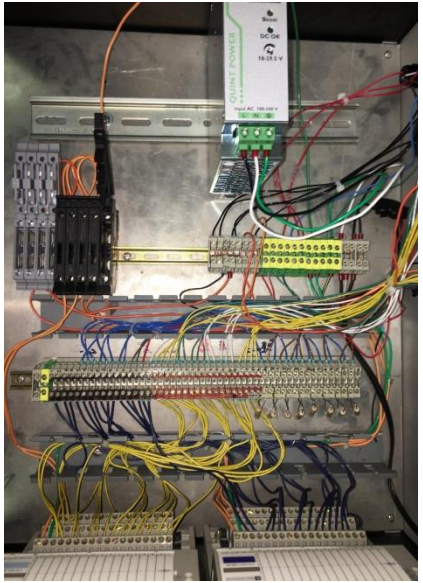
Process & Reliability Considerations

- Machining, soldering, welding done in highly-skilled TRIUMF machine shop
- Air connections and piping thoroughly leak checked
- Circuits and electrical connections verified rigorously



Manufacturing

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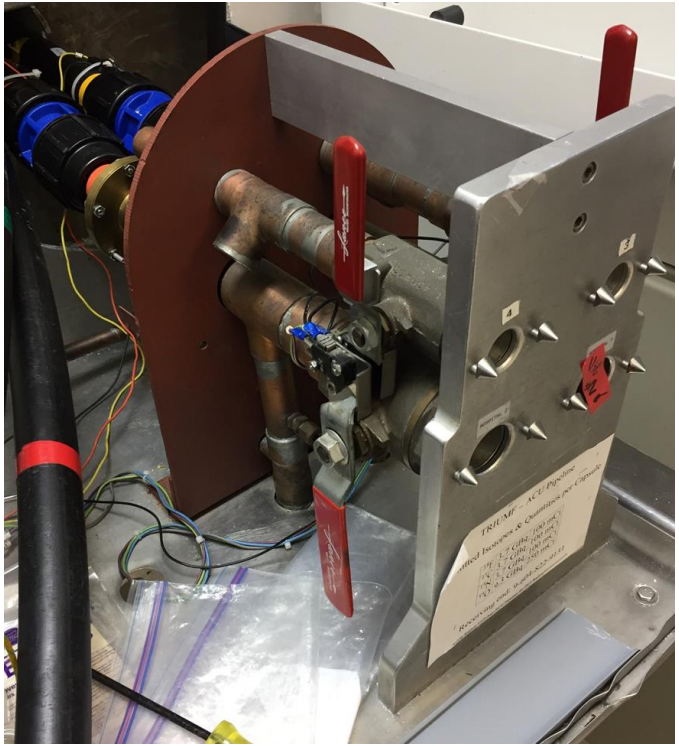

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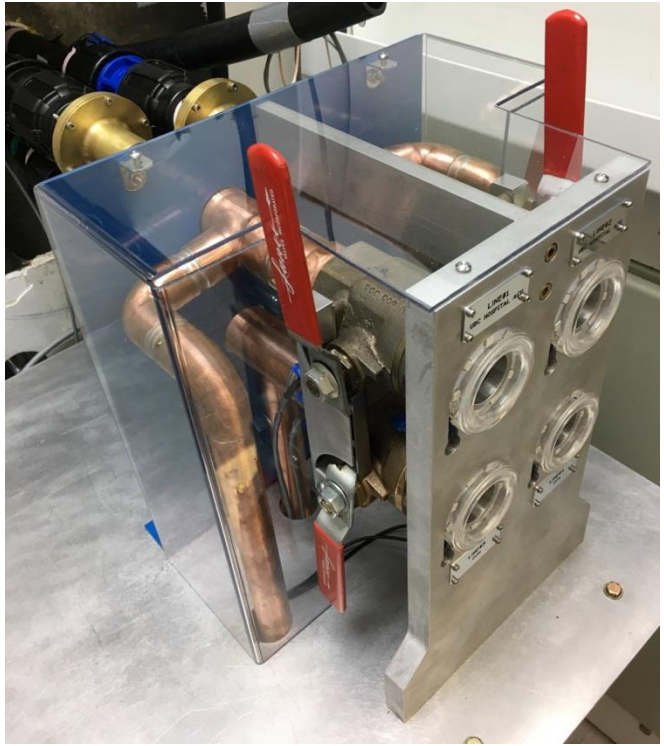

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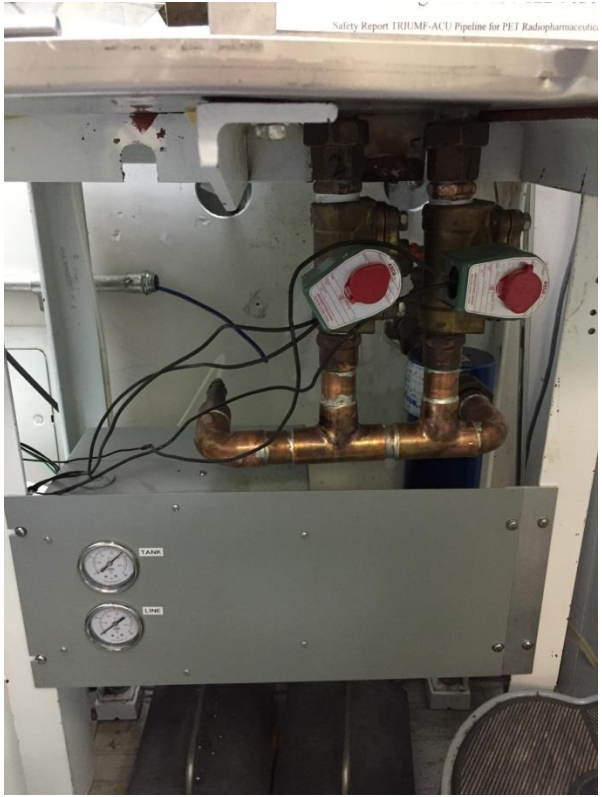

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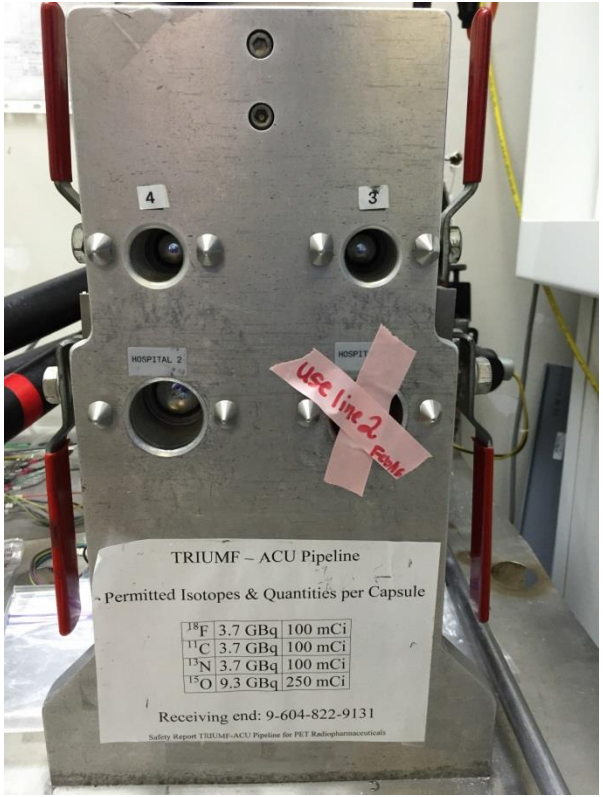

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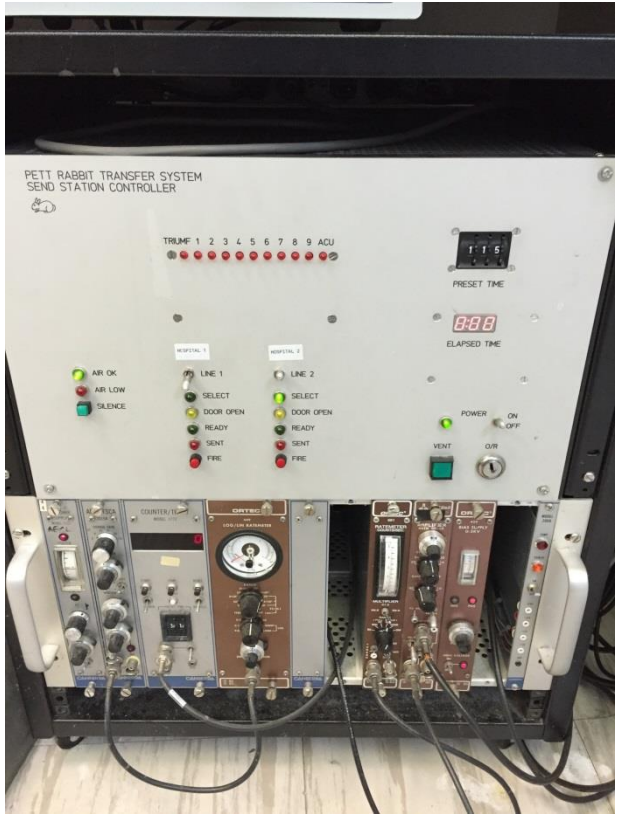

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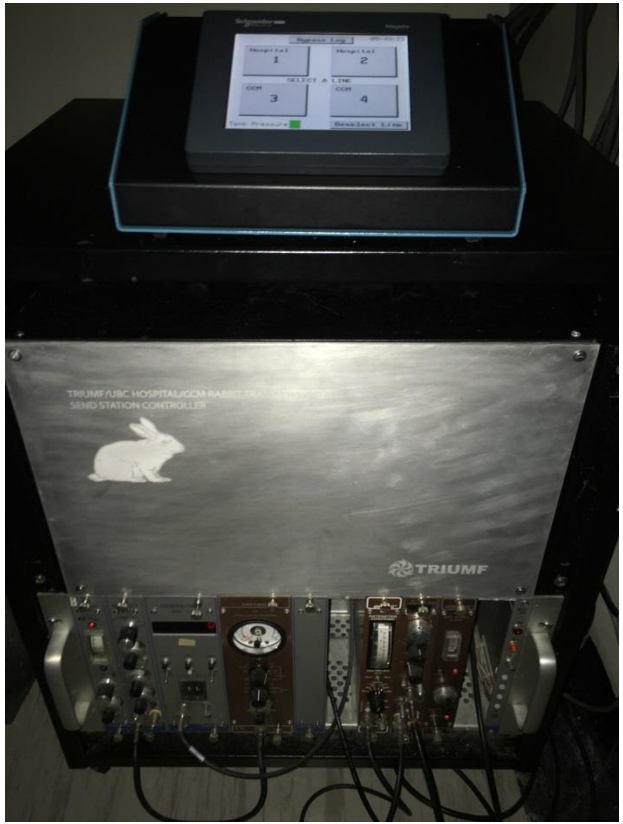

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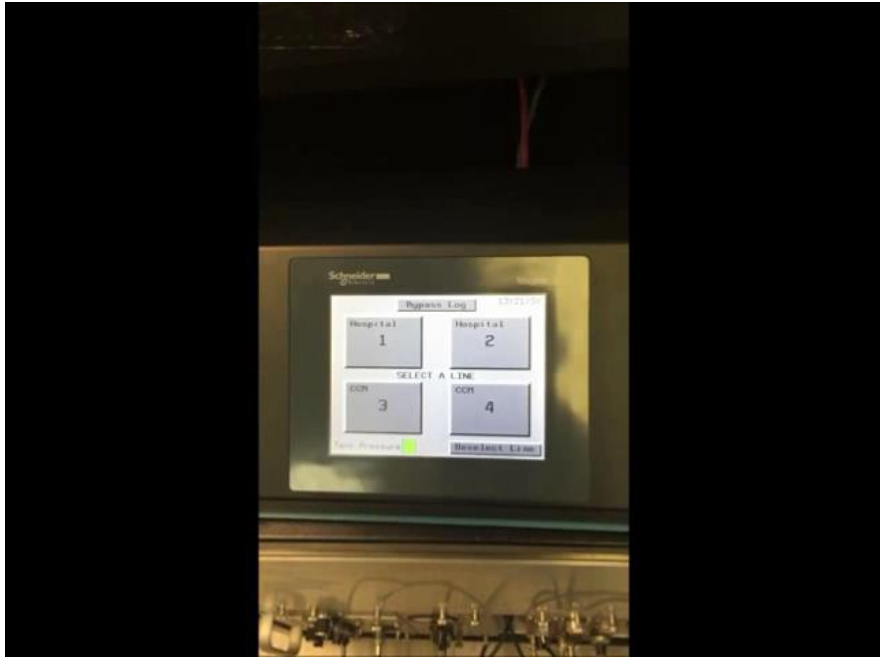
Process & Reliability Considerations

- Develop Commissioning Plan
- Emphasize tests for system reliability
- Test all functions and scenarios
- Have plan reviewed by technical experts and management
- Perform tests outlined in Commissioning Plan once system is manufactured
- Write Commissioning Report to record results and certify commissioned status
- If all test results are passed, system is deemed ready for operation
- Fully train all personnel who will operate and/or maintain the system

Upgraded Rabbit Line Send Station



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Thank You!
Merci!

Questions?