Reliability Considerations in Underground Isotope Transfer System Design

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• 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
- $t_{1/2}^{(11}\text{C}) \sim 20$ mins., $t_{1/2}^{(18}\text{F}) \sim 110$ 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

- (2x) 1” Ball Valves
- Valve Brackets holding door open/closed switches

- (2x) 1½” Ball Valves

- Line 1 & 2 Isolation Solenoid Valves

- Line & Tank Pressure Gauges

- “Pressure Box”

- 100 psi air from supply tank

- To Gauge

- To Lines

- Rabbit Line to Send Station Adaptors
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
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
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
• 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
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
• 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
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
Product Development Process

Steps
- Concept
- Design
- Assurance
- Manufacture
- Launch
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

<table>
<thead>
<tr>
<th>Component, Process, or Step</th>
<th>Potential Failure Mode</th>
<th>Potential Effects</th>
<th>Severity</th>
<th>Potential Causes</th>
<th>Likelihood of Occurrence</th>
<th>Controls/Mitigation</th>
<th>Undetectability</th>
<th>Risk Priority Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send Station</td>
<td>Pipe adaptor/Clamp Failure.</td>
<td>Rabbit line blows off from send station. Operator safety hazard.</td>
<td>9</td>
<td>O-ring failure, plastic rabbit line degradation, strain on adaptor.</td>
<td>2</td>
<td>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.</td>
<td>9</td>
<td>162</td>
</tr>
<tr>
<td>Send Station</td>
<td>Rabbit Delivered to wrong facility</td>
<td>Worst Case: Injured Chemist at destination, contamination spread. Best case: lost dose.</td>
<td>8</td>
<td>Operator error, not paying attention to labels and complacency.</td>
<td>8</td>
<td>HMI screen destination labels, destination labels above lines.</td>
<td>7</td>
<td>448</td>
</tr>
</tbody>
</table>

- Determined to be insufficient mitigation of accidental delivery risk
- Need a way to more fully engage operator in the sending process, guarding against complacency
• Integrate ring LEDs into rabbit line entrance design
• RGB lights can also display line conditions with different colours
• Bright visual cues, heightened operator engagement

<table>
<thead>
<tr>
<th>Priority</th>
<th>State</th>
<th>LED Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Line pressurized (Do Not Access)</td>
<td>RED</td>
</tr>
<tr>
<td>2</td>
<td>Line selected, to be loaded</td>
<td>GREEN</td>
</tr>
<tr>
<td>3a</td>
<td>Line loaded, solenoid interlocked</td>
<td>YELLOW</td>
</tr>
<tr>
<td>3b</td>
<td>Tank pressure low (all LEDs)</td>
<td>YELLOW</td>
</tr>
<tr>
<td>4</td>
<td>Line ready to send rabbit (Flashing)</td>
<td>GREEN (Flashing)</td>
</tr>
</tbody>
</table>
Product Development Process

Steps

- Concept
- Design
- Assurance
- Manufacture
- Launch
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
Product Development Process

Steps

- Concept
- Design
- Assurance
- Manufacture
- Launch
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
Thank You! Merci!

Questions?