Neutron Technologies Division
Nonconformance Request Form

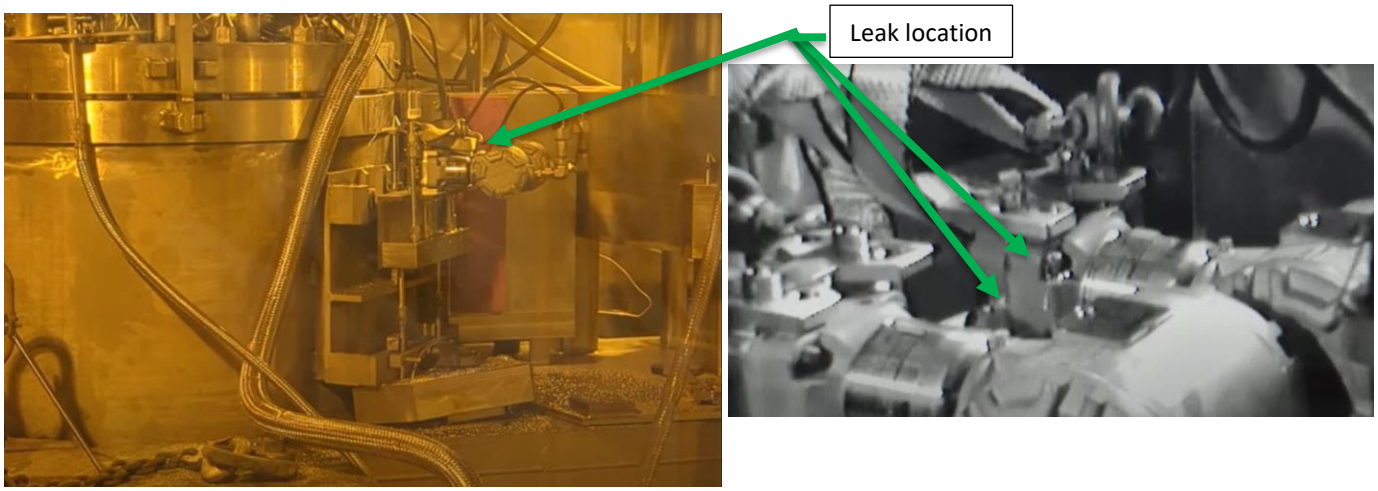
NR Number: 106010200-NCR10007

Date: 6/9/2024

Descriptive Title:
P-5001 Sensor Mercury Leak

PO or Work Order:
1661909

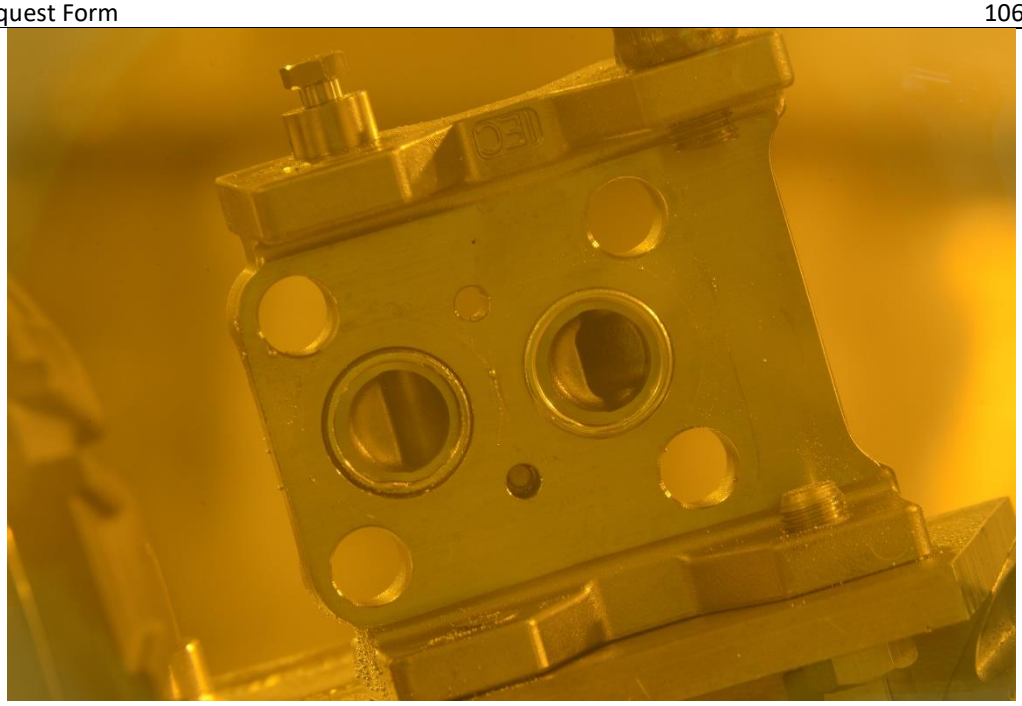
Description of Nonconformance:
On Thursday, May 30, 2024, at approximately 3:30am, the mercury vapor levels in the service bay began to increase from 20 µg/m^3. By 5:20 am, the mercury vapor level increased to 100 µg/m^3. Remote handlers later located the site of the mercury leak. The leak location was the back P-5001 mercury pump differential pressure sensor. Leaks from the mercury system are not compatible with on-going operation. The pressure sensors were leak tested before installation and operated for a time (on the order of days) without a leak.



The sensors are shown on drawing 106010202-M8E-8700-A273, Revision 5. The assembly includes three sensors. These are P-5161, the pump discharge pressure sensor, and P-5001A and P-50001B, the mercury pump differential pressure sensors. The differential pressure sensors are part of the credited Target Protection System. The sensors were installed during the current outage. This is the first use of this model number of sensors. The model number of these Rosemount differential pressure sensors is 3154ND4R2FIE7D3C3. Previously, two different model sensors were used. The first was a Rosemount sensor, model number 1154DP7RA. The second was an AMETEK PDH3200-100-J8-22-36-N2-00. The Rosemount 3154 series sensors were replacements for the 1154 series of sensors, as the 1154 are no longer manufactured. The change to the current sensors was evaluated using the SNS Equivalency Form for Credited Engineering Controls, as documented by 106080400-EQE10000. The change in the mechanical interface design was covered in 106010200-CN0006.

In a review after the occurrence of the leak, it was found in Rosemount Product Data Sheet 00813-0100-4514, Rev BA, for the Rosemount 1154 that the process seals in the previously used Rosemount 1154 series were constructed of 316L SST O-rings. Rosemount Product Data Sheet 00813-0100-4854, Rev AG, for the Rosemount 3145N series sensors states that the process seals in the new model line are silver-plated Inconel X-750 C-rings. Mercury amalgamates silver, and so the use of silver in the seals was thought to be the likely cause of the leak. The leaking sensor was disassembled to allow access to the seals. These seals were provided with the part and were not accessed until the sensor was disassembled in the service bay. They are internal design features, not something specified by the SNS.

Pictures of the seals are available at \\nscd\groups\NFDD\Neutron_Source_Development_Group\Target\PIE\Pictures - Hg Pressure Sensor. The seals showed signs of corrosion through mercury wetting and amalgamation. The high-pressure side of the sensor (left in in the picture below) showed significantly more corrosion than the low-pressure side (right in the picture below).



This supports the conclusion that the cause of the mercury leak is corrosion of the silver-plated Inconel X-750 process seals. These seals are present in the Rosemount 3145N sensors, including both P-5001 sensors that were installed during this run cycle. Due to this, it would be expected that the second of the P-5001 sensors would develop a leak soon if returned to service.

The purpose of this nonconformance is to address the incompatibility of the seals in these P-5001 sensors with mercury that resulted in the mercury leak on 5/30/2024, with the goal of determining a path forward for a return of the mercury loop to operation.

Lines below to be completed by SNS Responsible Engineer			
Nonconformance Risk Level: ☒ Serious ☐ Important ☐ Routine	USIE Required? ☐ Yes ☒ No	**USIE Document Number:** N/A	**Incorporate into Design Documentation:** ☐ Yes ☒ No

Evaluation of Nonconformance:

Replacement sensors are not currently available. The sensors operate in a high radiation environment inside the service bay and must be compatible with mercury. Rosemount will not provide sensors of alternative material that would be compatible with mercury.

An operable TPS is a requirement for beam operation. Therefore, it is necessary to find an alternative that will allow the TPS to return to operation. The TPS system uses several inputs, including differential pressure, pump power, and temperature. Alternative methods for addressing the different failure scenarios addressed by the TPS differential pressure sensors using the other inputs were reviewed. No method of addressing this case was found. For additional information on the setpoints cases addressed by the TPS sensors, see 106010200-DA0006-R02.

Returning to operation therefore requires a method for obtaining a differential pressure signal for the TPS. Alternative DP sensors have not been found that are compatible with the service environment, and the use of alternate sensors would likely require significant changes to the configuration of the wiring connections and other parts of the configuration of the TPS. In order to ensure the system would operate as intended, these changes would require significant review.

Returning the existing P-5001 sensors to operation would require the replacement of the silver-plated seals. As of 6/9/2024, Rosemount has not provided information on the seal geometry. Elastomer seals could be used in place of metal seals, but these seals have significantly reduced radiation resistance.

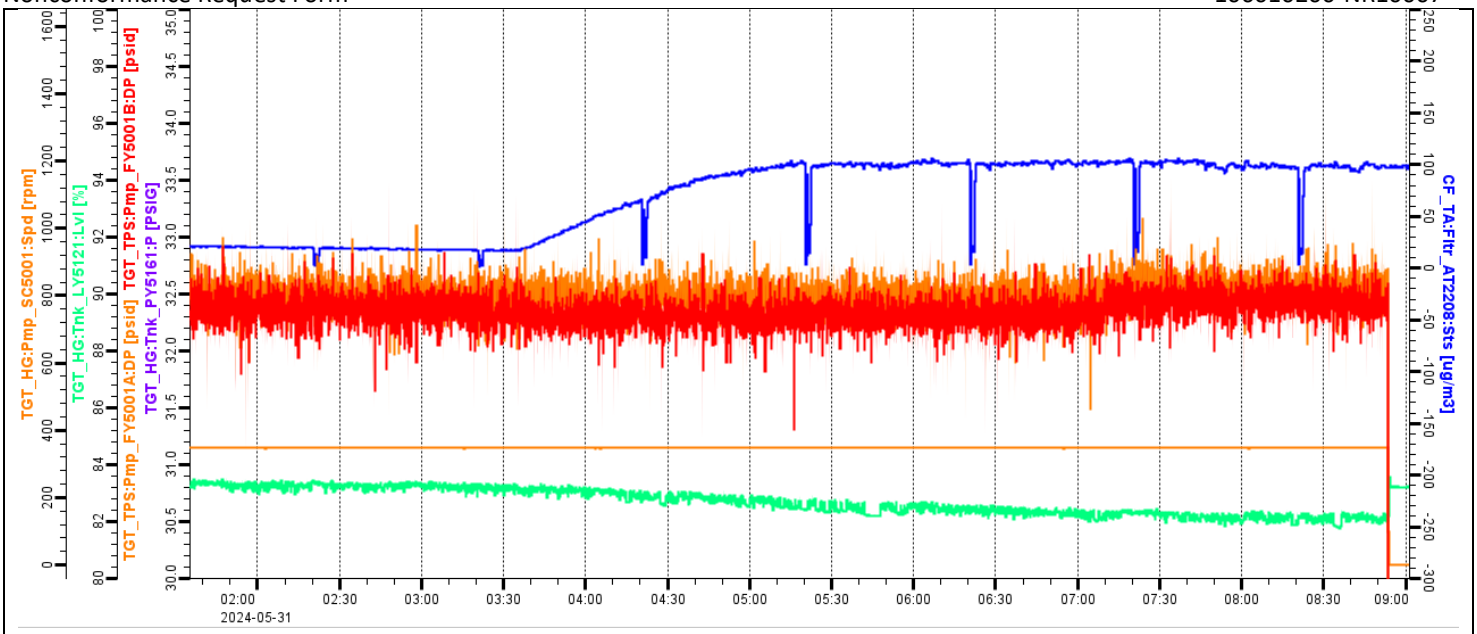
There are ion chambers located in the service bay that can be used to estimate the radiation dose to the sensors. The figure below shows the dose rates measured by two such ion chambers over approximately the past 2 years of operation. Note that the vertical axis is in log scale. The green trace is an ion chamber located by the mercury return pipe, under the shielding. The red trace is an ion chamber located on top of the mercury pump. The mercury pump has shielding that causes the reduction in the dose rates. The P-5001 sensors are located on the side of the mercury pump. Past approaches to estimating the doses on these sensors have reduced the dose rates measured at the top of the pump by a factor of 2 to reflect the differences in shielding thickness between the top and

side of the pump tank. [Reference email from Platfoot to Winder, 6/5/2024.] For this work, we will conservatively not include this reduction factor.

The peak dose rates over the period shown above were 1e3 Rad/hr. The next run cycle is approximately 5 ½ months long, providing a maximum total dose rate of 4e6 Rad over this period. This value is likely conservative. Available references [K. U. Vandergriff, "Designing Equipment for Use in Gamma Radiation Environments," Oak Ridge National Laboratory, ORNL/TM-11175, 1990] provide information on radiation resistance of different materials. For example, for SBR, radiation damage information spans from 2e6 to 6e7 Rad, which is around the calculated dose for the run cycle. Ethylene-propylene rubbers have similar experience with some formulations showing no degradation when tested at 5e6 Rad. Therefore, elastomer seals, while representing a reduction in effectiveness in withstanding radiation compared to a functioning metal seal, would have a reasonable expectation of lasting through the next planned run cycle. Given the reduced lifetime of the elastomer seals, these sensors should be replaced no later than the FY25A outage.

Parker's O-ring Handbook provides information about compatibility ratings for different elastomers with various process fluids. Mercury is listed as having "Satisfactory" compatibility with Nitrile NBR, Hydrogenated Nitrile HNBR, Ethylene Propylene EPDM, Fluorocarbon FKM, Hiflour FKM, Perflouroelastomer FFKM, Neoprene/Chloroprene CR, Styrene-Butadiene SBR, Butyl IIR, Butadiene BR, Isoprene IR, Natural Rubber NR, and Hypalon CSM. Other compounds were identified as "insufficient data", with no compounds being listed as unsatisfactory. This illustrates that mercury, while incompatible with many metals, is compatible with many elastomers.

In the case of failure of these seals, the failure mechanism would be expected to be similar to that seen with the leaking silver-plated seals. In that case, as shown below, the indications of a failure were mercury vapor (CF_TA:Fltr_AT2208) and level (TGT_HG:Tnk_LY5121). The differential pressure sensors both continued to report the same pressures, despite the leak in one sensor. If the leak was allowed to continue to grow, it could eventually affect the pressure reading, but the previous behavior provides assurance that any failures are likely to be detected before the TPS system no longer can perform its function.



Therefore, an elastomer seal may be used in place of the metal seals in the P-5001 sensors to allow operation of the existing TPS sensors. These seals should be replaced at the earliest opportunity but provide reasonable assurance to reach to the end of the next operating cycle.

Disposition:

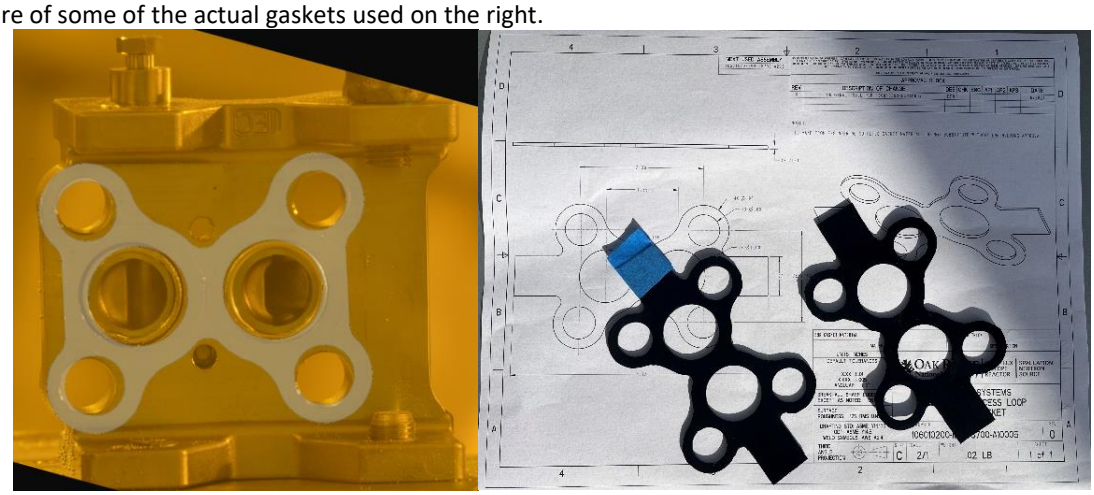
☐ Use As-Is ☐ Rework ☒ Repair ☐ Scrap

☐ Approved for Alternate Use (GL signature required)

Disposition Details:

Repair both P-5001 sensors by removing the existing silver-plated Inconel X-750 seals and replace with an elastomer gasket.

Drawing 106010200-M8U-8700-A10005 has been developed as a prototype gasket design. It uses 1/16” EPDM gasket material. The dimensions are based on measuring photographs and comparing to expected values, and so may have significant error when compared to actual sensor dimensions. The figure below shows a rough approximation of the gasket size and shape on the process flange on the left, and a picture of some of the actual gaskets used on the right.



The sensors were repaired by removing the silver-plated seals, and re-assembling generally per Rosemount Reference Manual 00809-0100-4835 Rev BG, Page 63, except using the gasket in place of the process C-rings, and not using torque tools to measure the applied torque. The seals were then pressure tested to verify assembly. See 106070100-WKI10010 for more details of the assembly and testing process.

The pressure testing showed no detectable leakage at 50 psig for the high-pressure volume, and at 30 psig for the combined high-pressure and low-pressure volumes. The sensitivity of this test is estimated to be on the order of 2e-3 torr*L/s of air. This test provides

assurance of correct assembly, but the sensitivity cannot completely guarantee there will be no leaks of mercury in operation, as this is roughly on par with the leak rates required for liquid mercury to escape [K. Haga, T. Naoe, H. Kogawa, T. Wakui, and M. Futakawa, "Mockup Experiments to Investigate the Leak Rate Correlation between Mercury and Helium for the Mercury Target System of J-PARC," Journal of Nuclear Science and Technology, vol. 46, no. 12, pp. 1145-1151, 2009, doi: 10.1080/18811248.2009.9711627].

These repaired sensors will now be returned to service. During initial operation, monitor for signs of leakage or unexpected signal response.

Responsible Engineer: Drew Winder 2024.06.13 11:51:20 -04'00'	**Quality Representative Required:** ☒ Yes ☐ No Tena A. Graben-Galyon Digitally signed by Tena A. Graben-Galyon Date: 2024.06.13 12:52:24 -04'00'
CEC System Engineer: Patrick Bong Digitally signed by Patrick Bong Date: 2024.06.13 12:11:31 -04'00'	**Accelerator Safety:** Jacob Platfoot Digitally signed by Jacob Platfoot Date: 2024.06.13 12:26:27 -04'00'
RAD Operations: Digitally signed by Michael J. Dayton Date: 2024.06.13 13:05:30 -04'00'	