BWX Technologies, Inc.

August 9, 2017
17-063

ATTN: Document Control Desk
Director, Office of Nuclear Material Safety & Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

References: (1) License SNM-42, Docket 70-27

Subject: 60-Day Written Report for Event Notification Number 52840

Dear Sir or Madam:

BWXT Nuclear Operations Group, Inc. - Lynchburg (BWXT NOG-L) is providing a 60-Day Written Report for Event Notification Number #52840 per 10 CFR 70.74 (b). The event notification was reported within 1 hour of discovery under 10 CFR Part 70 Appendix A (a)(4) – An event or condition such that no items relied on for safety (IROFS), as documented in the Integrated Safety Analysis (ISA), remain available and reliable in an accident sequence evaluated in the ISA, to perform their function.

On July 4, 2017, BWXT NOG-L staff identified an unknown quantity of high enriched uranium (HEU) in two desiccant containers associated with a glovebox air purification system in the Research and Test Reactor manufacturing area. The BWXT NOG-L Emergency Operations Center was subsequently activated and it was determined, based on conservative non-destructive assay measurements, that the containers may present a criticality risk. An ALERT was declared per the BWXT NOG-L Emergency Plan with notifications to the Commonwealth of Virginia, local officials of concern and the Nuclear Regulatory Commission. In conjunction with the emergency declaration to the NRC, BWXT NOG-L reported that the accumulation of HEU fuel in the desiccant containers represented an unanalyzed condition for which no safety controls were implemented as documented in the ISA under 10 CFR 70 Appendix A criterion (a)(4).

Following additional NDA measurements and NCS analysis, which determined HEU in the desiccant containers would remain acceptably subcritical in the as-found condition under all possible configurations, the ALERT was terminated on July 5, 2017. On July 5, 2017 a Level 1 investigation was launched to examine the event, identify root causes and corrective actions. The enclosed report provides an event description, a summary of our extent of condition reviews, a summary of our root cause investigation, our risk assessment of the event, and the related corrective actions.

If you have questions or require additional information, please contact Chris Terry, Manager of Licensing and Safety Analysis, at ctterry@bwxt.com or 434-522-5202.

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BWX Technologies, Inc.

Sincerely,

B. Joel Burch
Vice President and General Manager
BWXT Nuclear Operations Group, Inc. – Lynchburg

Enclosure

cc: NRC, Regional Administrator, Region II
NRC, Resident Inspector
NRC, M. Baker

Enclosure

60-Day Written Report for Event Notification #52840 - July 4, 2017

Event Description:

On July 4, 2017 at 15:36, BWXT Nuclear Operations Group - Lynchburg (NOG-L) activated the Emergency Operations Center (EOC) in response to the identification of an unknown quantity of high enriched uranium (HEU) in an air purification system during a maintenance activity on the system.

The purification system services the five Uranium Aluminide (UAl_x) powder production gloveboxes in the Research and Test Reactor (RTR) manufacturing area. In these gloveboxes, UAl_x HEU fuel is produced through a series of separating, crushing, sieving, weighing and measuring operations of coupons produced in the adjacent Arc Melt Furnace to achieve a homogeneous UAl_x product which will eventually be formed into compacted shapes and encapsulated in aluminum plates to support a variety of RTR product lines that utilize UAl_x fuel (e.g., ATR). The air purification system removes oxygen and moisture from the argon atmosphere maintained in the gloveboxes. The primary function of the purification system is to maintain oxygen levels in the gloveboxes below 4% to prevent a fire and maintain a negative pressure inside the gloveboxes for radiation protection concerns. The purification is accomplished through a desiccant material (molecular sieve - "White Media") which can collect up to 30% by mass of water and an aluminum/copper oxide ceramic (Q5 - "Black Media") that collects oxygen from the argon stream. These two purification materials are contained in two 18 ½ -inch tall by 19 ⅜-inch diameter cylindrical containers (desiccant containers) located in the bottom of a cabinet, separated by two inches, in the same room with the UAl_x glovebox. The purification system is connected to the UAl_x gloveboxes through piping on the top of the gloveboxes and argon is drawn from the glovebox through circulation pumps to in-service desiccant container and then returned to the UAl_x glovebox. The desiccant and aluminum/copper oxide ceramic are produced to last the lifetime of the purification system. The purification material is regenerated (oxygen and moisture removed) periodically by introducing regen gas into the desiccant containers and venting the moisture and freed oxygen to the room ventilation system which is serviced by a HEPA filter prior to discharge to the environment.

Upon arrival in the EOC, the Emergency Management Organization (EMO) determined through conservative Non-Destructive Analysis (NDA) measurements that the desiccant containers may present a potential risk of criticality. Therefore, the EMO declared an ALERT in accordance with the Mt Athos site Emergency Plan and notified Virginia Commonwealth state and local officials of the concern as well as the Nuclear Regulatory Commission. The ALERT was declared under the criterion "Loss of all parameters preventing criticality for which control cannot be immediately reestablished."

Throughout the evening of July 4th and into day of July 5th, the EMO was able to obtain more precise NDA measurements using gamma counting equipment as well as information about the chemical composition, density, and packing fractions of the air purifying media in the two desiccant containers. Nuclear Criticality Safety (NCS) calculation using this data demonstrated that the HEU in the desiccant containers would remain acceptably subcritical (below the normal condition k_{eff} license limit) in the as-found condition under all possible configurations. On July 5th at 18:57, the ALERT declaration was rescinded since the EMO had determined that there was no immediate risk of criticality or threat to the safety of workers or the public as a result of the event.

At 16:30 on July 4, 2017, BWXT NOG-L reported that the under 10CFR70 Appendix A criterion (a)(4) that the accumulation of HEU fuel in the desiccant containers represented an unanalyzed condition for which no safety controls were implemented as documented in the ISA.

Immediate Actions Taken:

The following actions were taken in response to this event:

- Spacing was provided between the two desiccant containers as directed by the NCS staff.
- Initial NDA measurements (based on E-600 count rates for a 2.5-liter bottle standard, 5-gallon bucket standard, and 55-gallon drum standard with known ^{235}U loadings) were taken of the two desiccant containers to determine the range of HEU fuel mass that may be present. These measurements estimated the fuel accumulation in the range of 100-1200 grams ^{235}U for the most heavily loaded container.
- The EOC was activated and an ALERT was declared in accordance with the Mt Athos Emergency Plan.
- Local, State, and NRC notifications were made as required by the ALERT declaration.
- The RTR radiation controlled area was isolated and appropriate access restrictions were implemented to ensure employee safety in the event of an actual criticality accident.
- Work in other Material Access Areas (MAAs) was suspended, and Extent of Condition reviews were performed to identify similar systems having potential for unexpected holdup. *Extent of Condition reviews are detailed in a section to follow.*
- Gamma spectroscopy measurements were taken with an instrument that permitted calculation of the quantity of HEU in the desiccant containers through coupled computer modeling. These measurements were repeated on numerous occasions with two separate gamma detection instruments during the response to, and investigation of, this event. This data was used in the NCS calculations of the as-found condition and as-installed configuration.
- Samples of new desiccant and aluminum/copper oxide ceramic were sent to an onsite laboratory to determine density, chemical composition, and packing fraction associated

with these materials. This data was used in the NCS calculations of the as-found condition and as-installed configuration.

- NCS calculations were performed which demonstrated the as-found condition was acceptably subcritical (below the normal condition k_{eff} license limit).
- The EMO rescinded the ALERT declaration based on the results of the NCS calculations for the as-found condition.
- The EOC remained fully staffed 24/7 until July 7th. The EOC continued to be staffed 24/7 with a Safety and Safeguards Director, Emergency Director and other essential positions thru July 14th.
- From July 17th to the completion of work, the EOC was staffed with Safety and Safeguards Director anytime RWP work was being performed on the desiccant containers.
- A Level 1 investigation team was chartered to perform the root cause analysis of the event.
- Additional NCS calculations was performed to assess "possible" but unlikely fuel configurations inside the two desiccant containers (i.e., in their as-installed configuration during operation). The associated NCS calculations varied physical properties of the air purifying materials (i.e., packing fraction, moisture content, etc.) and fuel configurations inside the containers. The results of the NCS calculations demonstrate a criticality accident was possible but highly unlikely. This work is summarized in the following paragraphs.
- Global extent of condition reviews were completed, and area restarts were authorized by Senior Management under the BWXT NOG-L Conduct of Operations procedure. *Extent of Condition reviews are detailed in a section to follow.*

Extent of Condition Reviews:

BWXT initially performed an Extent of Condition review to identify other air purification systems installed on equipment (gloveboxes and hoods) where unencapsulated fuel is processed. This review identified 21 additional purification systems across NOG-L that were assumed to not be part of the NCS analysis for the associated operations. Only one air purification system with a desiccant container that compared in size to the one in RTR was identified. The Filler area has a desiccant container with a volume of approximately 200 liters, but it has never been associated with fissile operations; it services a non-fuel system. The remaining air purification systems have desiccant containers ranging from 7.4 liters to 30.5 liters. These containers are of lesser volume than the ones identified on the UAl_x powder production glovebox in RTR, but are not of favorable geometry. The purification systems were surveyed with a gamma detection instrument and were determined to be free of fuel accumulations. The 21 purification systems were taken out of service.

A second Extent of Condition review was performed to globally evaluate all connections, inputs, and outputs from gloveboxes and hoods where unencapsulated fuel is handled at NOG-L. This Extent of Condition review focused on identifying any other possible fuel accumulations in ancillary systems attached to gloveboxes and hoods. The Extent of Condition review included visual inspections and gamma detection instrument measurements of any identified potential fuel accumulation areas. All systems that were identified through the Global Extent of Condition review were found to be free of fuel accumulations. However, additional gamma detection measurement points for the annual Nuclear Materials Control (NMC) ductwork survey were identified as part of the review. Area restarts were authorized by Senior Management under the BWXT NOG-L Conduct of Operations procedure.

A third Extent of Condition review related to the installation of glovebox ventilation pre-filters was performed. The objective of the review was to compare pre-filter installation methods to that of the Blend and Crusher gloveboxes in the HEU UAl_x powder production glovebox in RTR, where less than adequate design and installation of the 9" HEPA pre-filters assemblies was identified (see discussion in the *Investigation Summary* section).

Investigation Summary:

An investigation team was immediately established to review the event to determine the root cause(s). Initially the investigation focused on the determination of how the UAl_x HEU was able to migrate from the UAl_x HEU glovebox to the desiccant containers associated with the purification system.

The initial stages of the investigation identified a NCS analysis dated October 15, 1986 which established a routine operating limit of 600 grams for losses from the UAl_x HEU process that may accumulate in the purification system. The analysis recommended that, when losses reached 600 grams ^{235}U, all ^{235}U be removed before the operation continued. This 600 gram ^{235}U limit considered the upset condition of a failure of the heat exchanger allowing the unlimited supply of water as interstitial moderation within the desiccant containers. No credit was given for the robust construction of the heat exchanger. In addition, the 1986 analysis evaluated the normal condition where the only water available in the containers was limited to the capacity of the purifier desiccant material to retain moisture. This calculation showed that a mass of 8,000 grams ^{235}U remained below the 0.85 k_{eff} license limit for normal operations. The 1986 analysis documents NCS controls implemented for the purification process. However, the controls were not formally implemented through the ISA in accordance with current 10CFR70 - Subpart H requirements. The investigation could not determine exactly when or why the mass-loss monitoring control established by the 1986 analysis was discontinued. However, interviews with current and retired employees familiar with the analysis related that an event occurred in 1986 where a significant amount of UAl_x HEU was determined by Nuclear Materials Control (NMC) to have entered the purification system and deposited in the desiccant containers due to inadequate pre-filters (carburetor type) installed on the purification system lines. These employees stated that, as a result of the event, the purification system was cleaned out, removing all ^{235}U and the purifier media was replaced. This is the only recollection of the purifier media being replaced and the system being cleaned. Therefore, BWXT has determined the air purification system and associated purifier media have been collecting UAl_x HEU from the process since 1986 (~30-Years).

BWXT's investigation of how the UAl_x HEU accumulated in the purification system focused on the pre-filters installed to control UAl_x HEU from entering the purification system piping and eventually depositing in the purifier media which acted as a collection point for particulate passing through the purification system. An interview with a retired employee familiar with the process indicated that after the 1986 cleanout, the process restarted with carburetor type filters until new HEPA filters could be ordered. This statement leads BWXT to conclude that in 1986 upon restart that some amount of UAl_x HEU once again made its way into the purification system through the carburetor type filters which had already been proven ineffective in controlling fuel accumulations in the purification system. The retiree speculated, but could not recall specifically, that loses from the UAl_x HEU process were tracked and/or routine surveys were conducted of the purification system during this period until HEPA filters were installed, and the mass-loss monitoring control associated with the 1986 analysis was determined to no longer be necessary.

BWXT's investigation of the installed HEPA filters and inlet and outlet piping associated with the purification system identified that the pathway for UAl_x HEU fuel to have accumulated in the purification system was through less than adequate design and installation of the HEPA pre-filter assemblies. This allowed fuel to enter the desiccant through two paths, the three inch piping to the purifiers and the Argon Purge lines. Upon detailed examination of the 9-inch diameter pre-filters installed in the crushing and blending portions of the UAl_x HEU glovebox line and through discussions with the current operators, it was identified that the 9-inch pre-filters were particularly difficult to install and gain an effective seal against a spacer which had been installed on the ceiling surface of the glovebox. The investigation team observed that the 9-inch pre-filter installed in the crushing section of the glovebox has a significant gap (~ ¼ inch) between the spacer and the gasket of the pre-filter (Figure 1). In addition, the investigation revealed a gap between the spacer and the glovebox in the Blend Box and the assembly was loose fitting. These provided a pathway for UAl_x HEU into the purification system. This was confirmed by gamma measurements of the purification system piping which indicated accumulation of fuel beyond the 9-inch pre-filters. It is important to note, that at some point, the poor fit of the Crusher Glovebox 9-inch pre-filter must have been recognized by BWXT management because a second pre-filter (Figure 2) was installed on the glovebox outlet pipe to the purification system directly outside the crusher portion of the boxline. Measurements of the PVC piping installed downstream of the second filter indicate that this filter is effective in controlling UAl_x HEU from passing further into the purification pipe work and eventually into the desiccant containers.

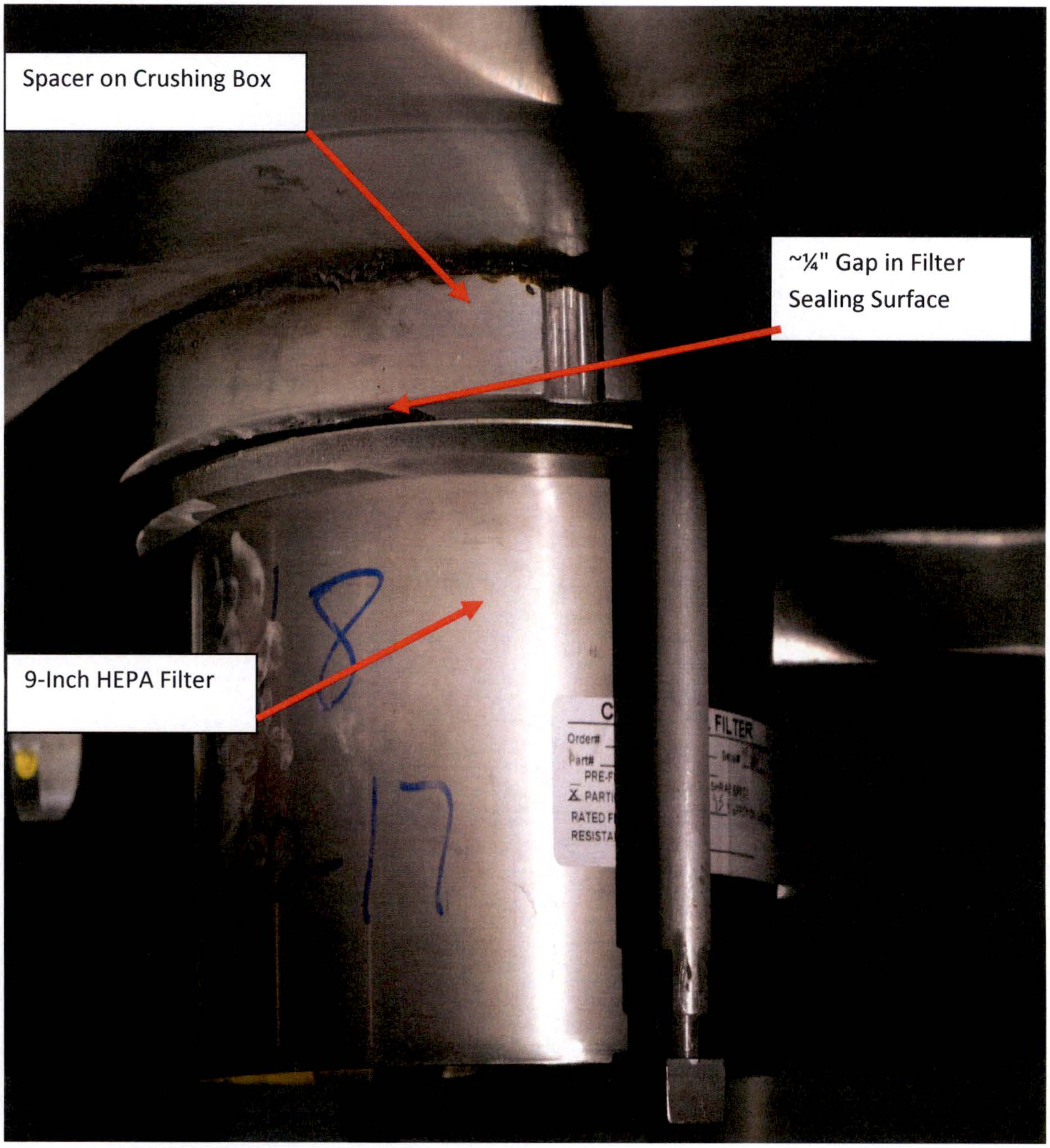

Figure 1 - Pre-Filter Installation in Interior of Crushing Glovebox

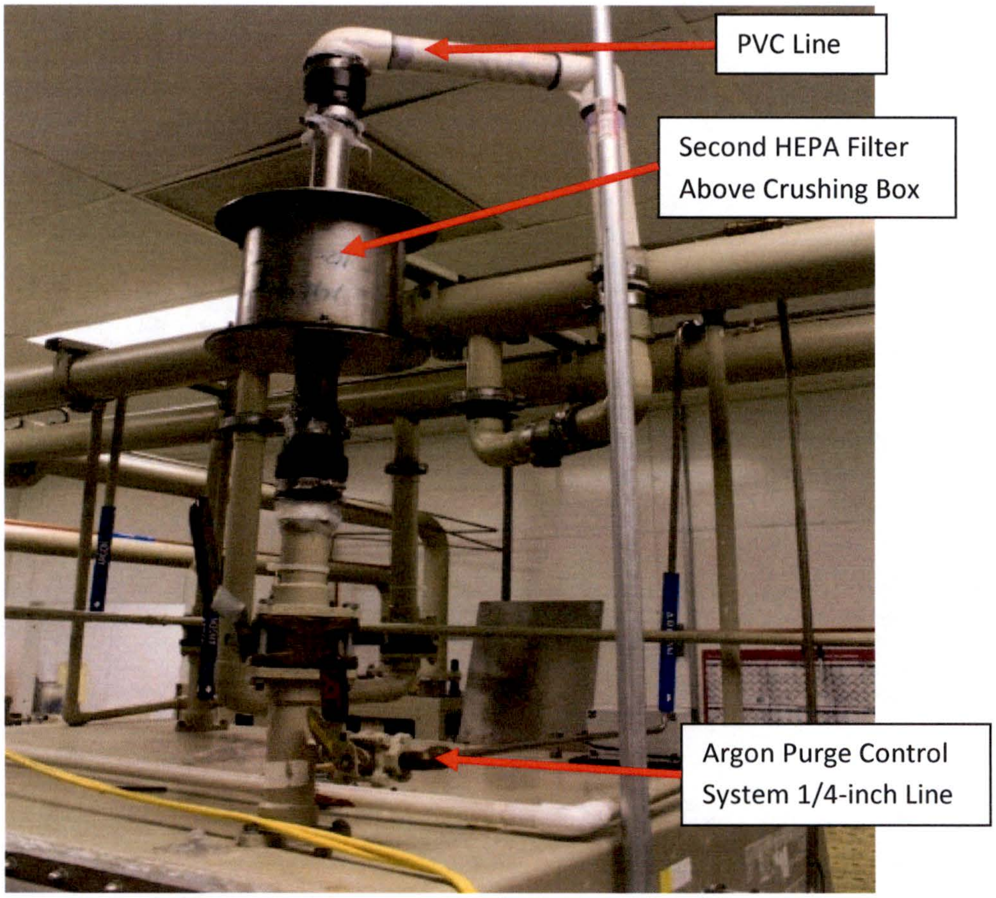

Figure 2 - Purification System Control Piping

The second pathway for UAl_x HEU to enter the purification system into the purifier media was through the purification system control piping (¼ inch Argon Purge line) that attaches to the main purification system piping (3-inch) on the outside of the UAl_x HEU glovebox directly above the 9-inch pre-filter described above (Figure 2). Similar to the leakage to the desiccant containers from the main purification system 3-inch piping, when the vacuum pump for the purification system is operating HEU can be drawn through the piping into the desiccant container.

The first root cause was identified through careful analysis of the effectiveness of the sealing of the 9 inch pre-filter design and installation. A root cause analysis, "An Unexpected UAl_x Accumulation In the Desiccant Containers of the Purification System Discovered During Maintenance," was performed using the TapRoot® methodology. This analysis identified two root causes.

- Root Cause (1) Less than adequate design and installation of the 9 inch HEPA pre filter assemblies in the Crusher and Blend Gloveboxes
- Root Cause (2) BWXT was not monitoring for buildup of ^{235}U or changing out the desiccant in the system purifiers on a periodic basis to ensure accumulations above the NCS limit did not occur as recommended by NCS in 1986.

- Root Cause (3) In 1998 the Dri-Train Vacuum system was not included in the original ISA review of the HEU UAlx Glovebox System.

This initial root cause investigation identified potential weaknesses with the Process Hazards Analysis and Integrated Safety Analysis (PHA/ISA), change management Safety Evaluation Request (SER) process, Extent of Cause reviews, and designation of uranium accumulations as "contamination" or "fuel." As a result of these concerns three additional events were identified for review to understand these potential weaknesses:

1. Original PHA/ISA for the UAl_x HEU process - This investigation focused on how the purification system and other ancillary systems were addressed in the PHA/ISA performed in 1998 to identify improvements needed in the PHA/ISA process.
2. Recent Safety Evaluation Requests (SERs) Involving Air Purification Systems - This investigation focused on SERs for gloveboxes that had air purification systems as part of their design. These changes were reviewed to determine if the ancillary purification systems were specifically addressed in the SER documentation submitted by the SER originator and subsequently reviewed by the safety evaluators. The purpose of the investigation was to identify needed improvements with BWXT's change management process.
3. Contamination Event - This investigation focused on a radiological contamination event associated with the movement of the UAl_x HEU process from one location to another. The event occurred when contamination fell from one of the disconnected air purification system control piping lines onto an individual. Although the contamination event was thoroughly evaluated the accumulation of UAl_x HEU fuel in this piping was not considered. The purpose of this investigation was to identify improvements in our event investigation (extent of cause) process as it relates to expected contamination levels and fuel accumulations.

The results of these investigations and the TapRoot® analysis of the originating event are included in Post Incident Review Team (PIRT) report 17-01. The corrective actions associated with the PIRT report are summarized later in this 60-day event report. In addition to these corrective actions the investigation identified a number of opportunities to identify and prevent the UAl_x HEU fuel accumulation in the purification system prior to the July 4, 2017 event.

Risk Assessment:

BWXT performed a risk assessment of the UAl_x HEU purification fuel accumulation using the guidance provided in NRC Inspection Manual Chapter 2606, "Assessment of the Risk Resulting from a Potential Safety Noncompliance at a Fuel Cycle Facility." The results of this risk assessment determined that although mass and geometry were not controlled, moderation control was present through an uncredited safety control. The likelihood of a criticality accident remained highly unlikely in accordance with BWXT's approved ISA methodology detailed in SNM-42.

The first step in assessing the risk presented by an accumulation of fuel material in the Dri-Train Air Purification System is to determine the ^{235}U mass values for the normal operating and upset conditions per the requirements of NRC License SNM-42. Standard material modeling practices for the BWXT NOG-L facility were applied to the calculations (Figure 3). Utilizing field measurements, the two desiccant containers were modeled as 18 ½ inch tall by 19 ⅜ diameter cylinders spaced 2 inches apart and 3 inches off the concrete floor. The container walls were modeled as ⅛ inch thick 316 stainless steel based on UT measurements of the wall thickness and vendor correspondence with respect to material of construction. The interior of the desiccant containers were modeled with a 2 ¾ inch lower plenum (based on field measurement) and purifier media filling the remainder of the cylinder. The purifier internals (i.e., inlet pipe to lower plenum, support plate, heating coils, etc.) were not modeled; the volume was filled with media material which provides a conservative result. Although the purifiers contained layers of two media types white (molecular sieve) and black (Q5), the purifier media types were analyzed independently. The chemical compositions, densities, and packing fractions of the media were based on laboratory analysis. The model included a tight fitting 12 inch thick water "wall" around the purification unit.

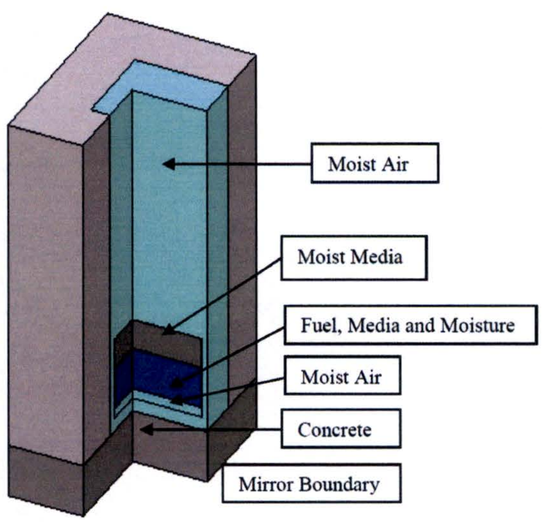

Figure 3 - Illustration of Model Geometry

The HEU fuel material was modeled with an enrichment of 93% ^{235}U in the form of UAl_2 to maximize the uranium density. In both the normal and upset cases the HEU fuel material is either 1) assumed to be distributed with cylindrical geometry having an H/D of 1 within the purifier media with variable fuel radius (which in turn defines the height) or 2) assumed to be uniformly distributed in the radial direction within the purifier media with variable fuel height. The latter distribution was confirmed by field measurements with a gamma assay instrument to be the most representative, whereas the former conservatively takes no credit for actual fuel distribution within the media. No fuel material was modeled in the lower plenum, whereas the upper plenum was assumed to be occupied by media and could contain fuel depending on the defined fuel geometry. Visual inspection of the plenums of both desiccant containers identified a light dusting. No significant fuel accumulations were observed. The amount of water retained in the purifier media for the normal condition is 8 weight percent based on the manufacturer's technical manual. During the moderation upset this value was increased to 30 weight percent based on the product specification for purifier media. The source of moderation during the upset condition is from the borated water used to cool the two heat exchangers in the purification unit. The borated water is maintained at a minimum ^{10}B concentration of 275 ppm. The influx of borated water fills the plenum and the media void space. The borated water coolant system is a currently existing IROFS credited in other accident sequences.

The amount of fuel material in the media void space for the normal and upset cases was increased until the k_{eff} limits of NRC License SNM-42 were achieved. The results of the analysis are summarized below in Tables 1 and 2. The mass values serve as the basis for assessing the risk resulting from the accumulation of fuel material in the Dri-Train air purification system.

Table 1 - Normal Condition with Even Radial Distribution			
SNM 42 License Limit	k_{adj} Value	^{235}U Mass (kg) per Container	
		White Media	Black Media
Normal Operating Limit	0.92	122	115
Safety Limit	0.95	134	126
Failure Limit	1.00	158	146

Table 2 - Upset Condition (Flooded with Borated Water) with Even Radial Distribution			
SNM 42 License Limit	k_{adj} Value	^{235}U Mass (kg) per Container	
		White Media	Black Media
Normal Operating Limit	0.92	2.05	2.60
Safety Limit	0.95	2.25	2.84
Failure Limit	1.00	2.61	3.29

The purification system and associated UAl_x glovebox line were installed in the mid-80s. In 1986 "a significant and consistent loss of fuel" occurred in the line. The event was analyzed by NCS in 1986 and it was recognized that there was a "possibility that the fuel is accumulating in ducts or within the gas purification system." A limit was established such that "whenever the accumulated loss approaches 600 grams ^{235}U, necessary steps be taken to assure that the loss has not accumulated in the purifier, and if it has, to remove all ^{235}U from it before operation is continued." There is no evidence that management measures were established long term to ensure the availability and reliability of this control in preventing an accumulation of fuel materials in the purifiers. Based on an interview with a retired Nuclear Materials Control (NMC) employee who was working in the RTR area during this time, the purification media was replaced in both containers following the 1986 event and has not been changed since. Interviews with a long term Operations employee who has worked with the glovebox line for the past 26 years indicated the media has not been replaced during his tenure. A review of the maintenance records for the glovebox line and Dri-Train air purification system provided no indication the purification media has ever been replaced. This is consistent with the manufacturer's technical manual which states the purification media should never have to be replaced unless chemical contaminants are introduced into the glovebox which deactivate the reactant material in the Dri-Train air purification system. It is apparent the purification media has been in service for over 30 years.

An effective rate of ^{235}U accumulation in the Dri-Train air purification system can be determined based on the mass of ^{235}U recovered from the desiccant containers over the operational history of the glovebox line. This assumption is based upon the noted accumulation over 30 years of operation. The actual measured ^{235}U content of Desiccant Containers #1 and #2 was 250.5 grams and 662.7 grams, respectively, or a total of 913.2 grams. A total of 0.9132 kg ^{235}U accumulating over 30 years is collecting at a rate of 0.03044 kg ^{235}U per year. This effective accumulation rate when combined with the previous mass values will determine the time required to accumulate the limiting mass values of Tables 1 and 2. These accumulation times are summarized below in Tables 3 and 4.

Table 3 - Normal Condition Mass Accumulation Time

NRC License SNM 42 Limit	k_{adj} Value	^{235}U Mass (kg) per Container	Total ^{235}U Mass (kg)	Accumulation Time (yrs)
Normal Operating Limit	0.92	115	230	7,556
Safety Limit	0.95	126	252	8,279
Failure Limit	1.00	146	292	9,593

Table 4 - Upset Condition (Flooded with Borated Water) Mass Accumulation Time

NRC License SNM 42 Limit	k_{adj} Value	^{235}U Mass (kg) per Container	Total ^{235}U Mass (kg)	Accumulation Time (yrs)
Normal Operating Limit	0.92	2.05	4.10	135
Safety Limit	0.95	2.25	4.50	148
Failure Limit	1.00	2.61	5.22	171

The steps in the risk assessment follow the guidance of IMC 2606 Section 06.01 - Assessing Risk Following a Potential Noncompliance.

a. <u>Identify the Accident Sequences or Contingencies</u>

The accident sequence that is the focus of the risk assessment is the chronic accumulation of HEU UAl_x fuel material in the unfavorable geometry desiccant containers. An acute accumulation of significance to present a criticality concern would be detected by NMC processing monitoring and six month inventory controls, and there is inherently lack of motive force for such a significant accumulation to occur over a short time-frame. Contamination levels of uranium materials are expected to accumulate in the containers. The accumulation of significant quantities of HEU UAl_x fuel material in the containers is an upset condition.

b. Identification and Consideration for Controls

The chronic accumulation of HEU UAl_x fuel material in a large enough quantity to result in a criticality accident would occur over an extended period of time. The rate of accumulation in the desiccant containers is the result of the natural and credible course of events based on physical arguments and the nature of the process (i.e., inherent lack of motive force for significant accumulation over short time periods and aspects of the pre-filter installation). The media in the desiccant containers acts as a filter to trap the fuel material. Based on field observation of the containers, the fuel material only collected within the media, not the plenum region below or the void space above the media. The most plausible pathway for the material to reach the containers is through the glovebox outlet lines to the purification system. These lines are protected by HEPA pre-filters which are changed on a periodic basis. The pre-filters are designated as IROFS to prevent accumulation of uranium materials in the ventilation system. Detailed examination of two of the pre-filters revealed an improper installation which created a gap between the filter gasket and the glovebox interior wall. The improper installation of the filters appears to be the result of a flaw in the glovebox design. The inadequate installation allowed the material to bypass the filters which degraded their effectiveness as an IROFS. This was confirmed by gamma survey of glovebox outlet lines which revealed elevated readings. It was further verified by gamma surveying all other glovebox prefilter post filtration and demonstrating at or near background levels.

Moderating material is present in the desiccant containers during normal operation. One function of the purification media is to remove water from the glovebox atmosphere. This normally existing level of moderation was accounted for in the NCS evaluation of the air purification system. Another credible source of moderation is the cooling water supplied to the Dri-Train air purification system's two heat exchangers. Heat is introduced into the gas flow from blowers that circulate the glovebox atmosphere through the purification system. The heat exchangers cool the gas flow before it returns to the glovebox. The heat exchanger coolant is essentially an unlimited supply of water during a moderation upset.

The heat exchanger is an un-credited passive engineered control (Figure 4). The design of the heat exchanger provides an extremely high degree of reliability and protection from a coolant leak (Figure 5). The glovebox atmosphere passes through the larger diameter tube of the heat exchanger. Heat is conducted to the tube wall by a heat exchange assembly which is formed by a central expanded tube and a fin construction. Water flowing through an external cooling coil encircling the larger tube provides a source of coolant to the heat exchanger. The heat exchangers were leak tested to verify the integrity of the tubing. No leaks were identified. X-ray evaluation of the heat exchangers confirmed the interior configuration and detected no signs of degradation in the tube walls (Figure 6). For water to enter the gas stream, the wall of the water line and the gas line must fail simultaneously at adjacent points. The probability of this combination of failures is extremely remote.

Figure 4 - Heat Exchanger Installed in Dri-Train Air Purification System

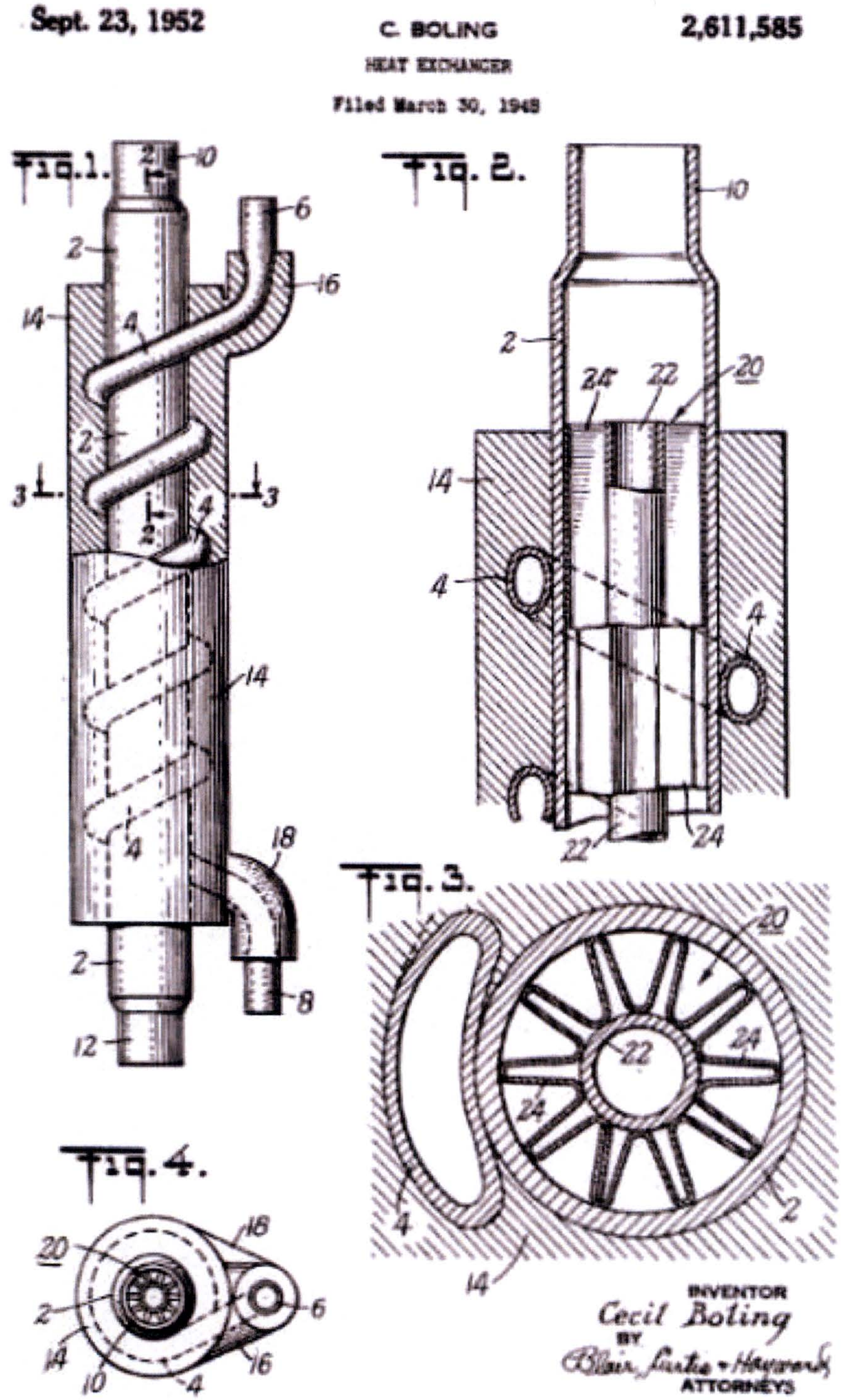

Figure 5 - Patented Heat Exchanger Design (reference patent number 2,611,585)

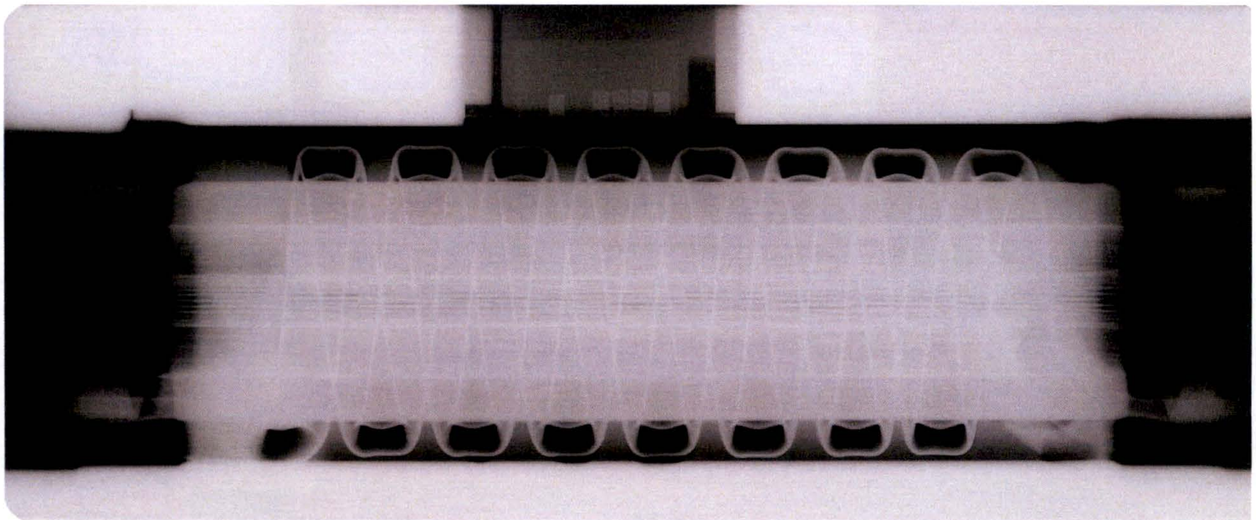

Figure 6 - X-ray Image of Dri-Train Heat Exchanger

The introduction of coolant to the desiccant containers could seriously damage the purification system and possibly result in personnel injuries. The saturation of the purification media with water results in a violent exothermic reaction. The supplier of the Dri-Train air purification system indicated this heat exchanger design was used in their products from the early 1960s until 2003. The manufacturer stated they have "hundreds, if not thousands, of these heat exchangers installed in our products at installations all over the world. To the best of our knowledge, there has never been a failure of the heat exchangers at the factory or in the field that allowed water to enter the gas circulation path."

The heat exchangers are cooled by a borated water coolant system. The borated coolant system is an existing IROFS credited in other accident sequences. Appropriate management measures are in place to ensure the system is reliable and available. The ^{10}B concentration is verified by laboratory analysis on a periodic basis and adjusted as necessary. The neutron poisoning effect of the ^{10}B in the coolant system was included in the NCS evaluation of the moderation upset.

c. Assess the Consequence

The consequence of the chronic accumulation of a significant amount of HEU fuel material in the desiccant containers is a criticality accident, particularly when concurrent with a moderation upset.

d. Assess the Likelihood

The likelihood of a criticality accident based solely on the accumulation of fuel material in the desiccant containers presents no risk. Per the guidance of FCSS Interim Staff Guidance-01, Rev. 0, "Qualitative Criteria for Evaluation of Likelihood," facility or process features (or physical and chemical) phenomena that can affect the initiating event likelihood may be identified as initial conditions or bounding assumptions. The rate of accumulation of HEU fuel material in the desiccant containers is bounded by the noted accumulation over 30 years of operation. There is considerable margin in the mass required to exceed the SNM-42 Safety Limit. A total of 252 kg ^{235}U (126 kg ^{235}U per desiccant container) must accumulate in the Dri-Train air purification system. The time to accumulate this amount of ^{235}U is 8,279 years based on the rate of accumulation over the last 30 years of operation. This time period far exceeds the life of the facility. A mass of 252 kg represents significant safety margin between the amount of ^{235}U likely to be encountered during normal or credible abnormal conditions and the value that would allow an accident to be possible. The margin is several times larger than the expected process variation or uncertainty. Therefore, the likelihood of a criticality due to a chronic accumulation of strictly fuel material in the desiccant containers is highly unlikely.

The likelihood of a criticality resulting from the chronic accumulation of a significant amount of HEU fuel material in the desiccant containers during a moderation upset will be determined using BWXT's ISA methodology. BWXT's ISA methodology defines the Overall Accident Likelihood as the Frequency of the Initiating Event – the Effectiveness of Protection (Table 5). The Initiating Event Frequency for this accident sequence is assigned a "-2" (not expected, but might occur during plant lifetime) considering the extended time (171 years) necessary to accumulate the mass of ^{235}U necessary for a criticality to occur during a moderation upset. The degraded IROFS of the glovebox pre-filters is not credited as preventing this accumulation. The pathway created by the inadequate design for installation of the pre-filter allowed the uranium fuel material to bypass the filter and reach the desiccant containers.

An Effectiveness of Protection score of "3" is assigned to the moderation control provided by the design of the heat exchanger. For water to enter the desiccant containers, the wall of the cooling water line and the gas line must fail simultaneously at adjacent points. The heat exchanger is an un-credited safety control. It has the reliability and availability qualities of a passive engineered control combined with an extremely low rate of failure rate. There are no known failures of at least hundreds, if not thousands of these heat exchangers in its 40 yrs of use in Dri-Train and similar purification systems.

Table 5 - Risk Reduction Matrix					
Accident Sequence	**Controls**	**Control Type**	**Initiating Event Frequency**	**Effectiveness of Protection**	**Overall Accident Likelihood***
Chronic accumulation of significant quantity of ^{235}U (~171 years worth of accumulation) in purification system due to bypass of glovebox pre-filters	N/A	N/A	-2	N/A	-5
	Heat exchanger design controls moderation	Un-credited passive engineered safety control	N/A	3	

* The Overall Accident Likelihood for the accident sequence is a "-5" [(-2) - (3)]. An Overall Accident Likelihood of "-4" or less is "Highly Unlikely." This risk assessment is summarized in the table above.

Corrective Actions:

As previously stated, a PIRT investigation was performed of the event using the Tap Root® and from that initial investigation NOG-L Management directed the investigation of other events that would inform the appropriate corrective actions necessary to adequately address the root causes identified. NOG-L Management has identified the following subset of commitments from the investigation reports and management review of the event as appropriate regulatory commitments to resolve this event and prevent reoccurrence.

1. Revise the PHA/ISA process/procedures to ensure appropriate design information is available and reviewed to allow for the assessment of fuel accumulation in ancillary systems supporting fuel operations. (12/1/17)
2. Revise the SER process/procedures to ensure ancillary systems supporting fuel operations are specifically addressed in the change process to identify and evaluate potential fuel accumulation in ancillary systems. (11/1/17)
3. Establish division level requirements for the installation and maintenance of pre-filters installed on ventilations and ancillary systems to adequately limit fuel entry into these systems. As a minimum this procedure will address minimum design requirements, replacement schedules, and monitoring of fuel loading to identify upset conditions. (1/1/18)
4. Implement a program for identifying all penetrations in gloveboxes and ventilation hoods for ventilation and ancillary systems. This program will require the change management

program to be used for all new and modified penetrations. Field marking will be provided for all penetrations. (1/15/18)

5. Review the Annual Ductwork Survey procedure for improvements and revise the procedure as necessary to control additions and revisions to the procedure through the change management program. (1/15/18)
6. Develop and implement a NDA method to assess the accumulation of fuel in ancillary systems. This method will provide a conservative threshold above which investigations will be implemented to determine if fuel has accumulated. In addition, a periodic surveillance program will be developed using this NDA method. (2/15/18)
7. Evaluate the adequacy of drawing and P&ID requirements which support QWI 5.1.12 "Change Management" and QWI 2.1.3 "Integrated Safety Analysis Methodology." (6/1/18)
8. Redesign and replace the 9 inch HEPA pre-filter assemblies on the Crusher and Blend Glove boxes prior to returning them to operation. (6/1/18)
9. Modify the Radiation Work Permit procedure to specifically require RWP request originators and evaluators to consider the potential for fuel accumulations in ancillary systems servicing processes being addressed under the RWP. The RWP program will be modified to direct the inspection of potential fuel accumulations using the NDA method established in corrective action number 6. (10/1/17)
10. Complete and document an extent of cause review for all root causes identified in the PIRT investigation. (6/1/18)