

Design of a Tritium and Iodine Removal System for Use with Advanced Tritium Pretreatment

**Nuclear Technology
Research and Development**

***Prepared for
U.S. Department of Energy
Material Recovery and Waste Form
Development Campaign
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28 February 2017***

**NTRD-MRWFD-2017-000311
ORNL/SR-2017/116**



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SUMMARY

US regulations will require the removal of iodine and tritium, along with other volatile and semi-volatile radionuclides, from the off-gas streams of nuclear fuel reprocessing plants. Advanced tritium pretreatment (TPT) is an additional head-end operation that could be incorporated within nuclear fuel reprocessing plants. It utilizes nitrogen dioxide (NO_2) as an oxidant to convert UO_2 to U_3O_8 prior to traditional aqueous dissolution. Advanced TPT can result in the quantitative volatilization of both tritium and iodine. Up-front removal of iodine is of significant advantage because otherwise it distributes to several unit operations and the associated off-gas streams. The off-gas streams will then require treatment to comply with US regulations. Advanced TPT is currently under development at Oak Ridge National Laboratory, and a kilogram-scale hot cell demonstration with used nuclear fuel (UNF) is planned for fiscal year (FY) 2018.

The off-gas stream generated by advanced TPT will contain high levels of NO_2 in addition to iodine, tritium, and other volatile and semi-volatile radionuclides contained in UNF, including $^{14}\text{CO}_2$, ^{85}Kr , and Xe. As part of the FY18 demonstration, off-gas treatment methods for the advanced TPT off-gas (ATPOG) to recover tritium and iodine and to separate them from one another will be developed and demonstrated. This report is intended to assess the stream and to identify potential treatment approaches that could remove iodine and tritium from the ATPOG. Preliminary system designs are provided as a first-step toward the development of the system intended for use in the kilogram-scale demonstration.

Results of the stream assessment indicate that iodine could exist in the ATPOG at a maximum concentration of 2,700 ppm. Online removal of iodine from the advanced TPT recirculation loop could lower this concentration significantly. Silver-nitrate impregnated alumina was identified as a promising sorbent for this application and preliminary bed sizes were determined.

Tritium could exist within the ATPOG at a maximum concentration of 25 to 50 ppm and will be found as either tritiated nitric acid (at temperatures below 50°C) or tritiated water (at temperatures above 250°C). Given the dilute concentration, it was determined that allowing the tritium to build up to the maximum concentration within the advanced TPT recirculation loop and treating a bleed stream upon the conclusion of testing was the most promising approach to effect quantitative tritium removal.

A number of materials were identified as potential nitric acid or water sorbents. For nitric acid, removal would be conducted at lower temperatures and sorbents to be tested include nylon fibers, silica gel, and 5A molecular sieves. For water removal at high temperatures, 3A molecular sieves and silica gel were identified as candidate materials. Scoping tests on each of these sorbents will be completed in FY17. The composition of the ATPOG is unique given its high NO_2 concentration, and thus data on the potential tritium sorbents are largely unavailable for applicable conditions.

The scoping studies described in this report are intended for completion in FY17. The results will be used to identify the most promising tritium removal methods for use in the treatment of the ATPOG. Additional work to more fully characterize the sorbent technology may be necessary prior to a detailed design of the hot cell system. Any additional R&D will be completed on a time line that will facilitate incorporation of the removal technologies into the planned advanced TPT demonstration in FY18.

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ACRONYMS

3AMS	3A molecular sieve
ATPOG	advanced tritium pretreatment off-gas
DF	decontamination factor
FTIR	Fourier transform infrared spectrometry
FY	fiscal year
ORNL	Oak Ridge National Laboratory
TPT	tritium pretreatment
UNF	used nuclear fuel

DESIGN OF A TRITIUM AND IODINE REMOVAL SYSTEM FOR USE WITH ADVANCED TRITIUM PRETREATMENT

1. INTRODUCTION

US regulations will require the removal of iodine and tritium, along with other volatile and semivolatile radionuclides, from the off-gas streams of nuclear fuel reprocessing plants. In traditional aqueous reprocessing of used nuclear fuel (UNF), the volatile fission products are released during the acid dissolution step. Some of the volatiles are partially soluble in the aqueous solution; tritium is converted to water to become part of the water circulating within the plant. Consequently, the fission products (or compounds thereof) may distribute into the off-gas streams of multiple unit operations, with each off-gas stream having different chemical compositions, radioisotope inventory, temperatures, volumetric flow rates, and requirements for treatment. Because tritiated water can be separated from the plant water only by an isotopic separation technique, tritium pretreatment was devised to separate and recover the tritium in a dry process before the fuel would be introduced to the aqueous dissolution step, thus avoiding its migration to other unit operations and off-gas streams.

Traditional dry tritium pretreatment (TPT) oxidizes the UO_2 -based UNF with oxygen, usually in concentrations ranging from that in ordinary air to pure oxygen. In dry TPT, the UO_2 is converted to U_3O_8 , quantitatively releasing the tritium and converting it to water vapor, which may then be removed from the process off-gas with solid molecular sieve sorbents. Traditional TPT is conducted at high temperatures (600°C) and takes an extended period of time to conduct full fuel oxidation.

Advanced TPT is a variation on air TPT and utilizes nitrogen dioxide (NO_2) as the oxidant. It results in the quantitative volatilization of both tritium and iodine. Up-front removal of iodine is of significant advantage because otherwise it distributes to several unit operations and the associated off-gas streams. Other advantages of the process include improved oxidation kinetics at lower temperatures, which reduces the heat-up time and the space time of the material in the reactor, both of which ultimately reduce the size of the processing equipment. Advanced TPT is currently under development at Oak Ridge National Laboratory (ORNL), and a kilogram-scale hot cell demonstration with UNF is planned for fiscal year (FY) 2018.

The off-gas stream generated by advanced TPT will contain high levels of NO_2 in addition to iodine, tritium, and other volatile and semi-volatile radionuclides contained in UNF, including $^{14}\text{CO}_2$, ^{85}Kr , and Xe. As part of the FY18 demonstration, off-gas treatment methods for the advanced tritium pretreatment off-gas (ATPOG) to recover tritium and iodine and separate them from one another, will be developed and demonstrated. In this initial demonstration there is no requirement to capture the CO_2 , ^{85}Kr , or Xe. This report is intended to assess the stream and to identify potential treatment approaches that could remove iodine and tritium from the ATPOG. Preliminary system designs are provided as a first-step toward the development of the system intended for use in the kilogram-scale demonstration.

2. Expected Composition of Advanced TPOG Off-Gas Stream

An analysis of the amount of radionuclides present in the fuel was carried out to determine the concentrations of iodine and tritium in ATPOG, and the design of the expected advanced TPT system was completed. This was performed with information provided in Johnson and DelCul (2016) and information gained from subsequent conversations with the authors regarding plans for the kilogram-scale demonstration.

2.1 Design assumptions

The flowsheet for the advanced TPT demonstration is shown in Figure 1. The reaction vessel will be contained within a hot cell, but the off-gas traps are expected to be contained in a heated enclosure external to the hot cell. An oxidation reaction converts the UO_2 to U_3O_8 , reducing the NO_2 to NO . Addition of oxygen in the cooler portions of the flow circuit converts the NO back to NO_2 . In effect, this permits oxygen to be the primary consumable reagent, with the oxygen reporting to the condensed solid phase U_3O_8 . Oxygen flow is adjusted to maintain a constant pressure in the system. The volatile fission products released from the fuel represent only a small volume, making containment of the gases within a closed circulation loop practical. This results in fission product gases accumulation at higher concentrations than is possible in systems using flow-through air as the reagent. The treatment system piping is designed to accommodate two modes of operation. In one mode, the process gases are circulated in a closed loop until the fuel is fully treated, and then the gases are routed through the off-gas trapping system. In the other mode, the process gases may circulate through the trapping systems while the fuel is being treated. In the latter mode, an online oxygen sensor located within the heated enclosure may be used to track progress of the reaction. The gas volume of the recirculation loop was estimated to total 5 L, as is shown in Table 1. The gas flow rate is expected to be 2 L/min. Additional system volume associated with the off-gas trapping components (located in the out-of-cell enclosure) will not be estimated in this design effort.

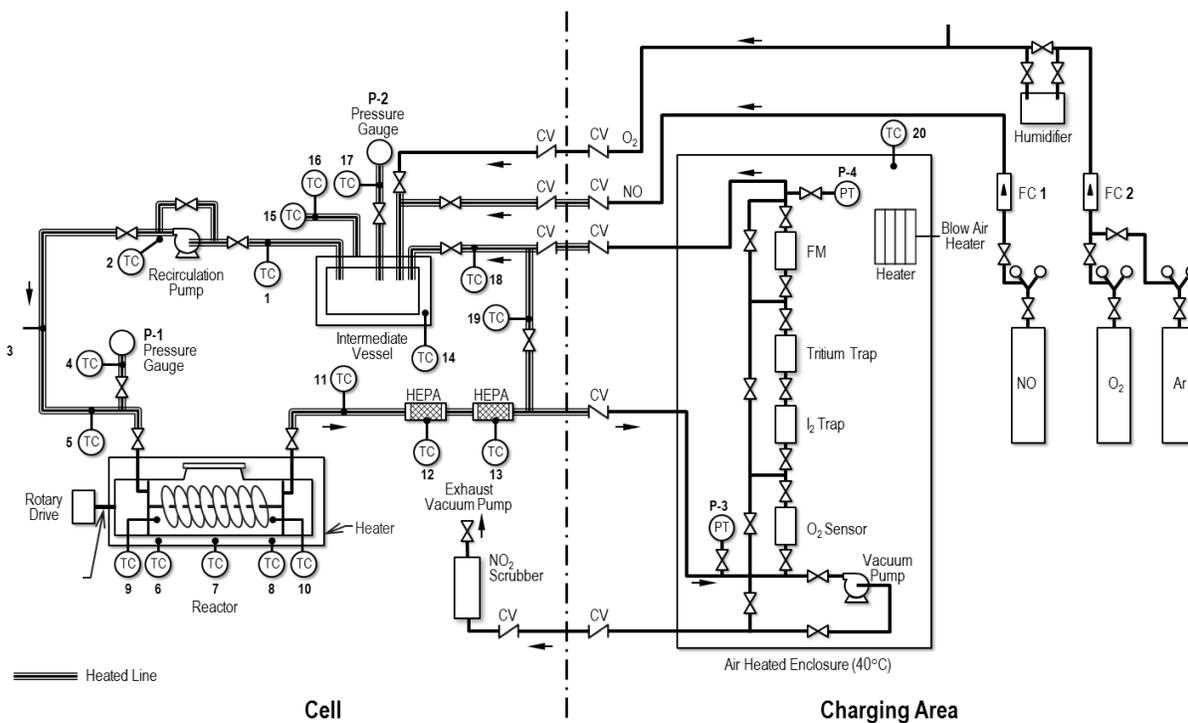


Figure 1: Flowsheet for NO_2 treatment at ORNL's Building 3525. (Johnson and DeCul 2016)

Table 1: Estimation of gas volume for advanced TPT demonstration system

Recirculation loop components	Volume (L)
Reactor	1
Intermediate vessel	3
Connecting tubing	1
<i>Total</i>	5

2.2 Fuel composition and expected concentration of the components to be removed

To estimate the amount of volatiles released from the UNF, the following bases were assumed:

- Pressurized water reactor fuel,
- Burnup of 55 GWd/MTIHM,
- Cooling of 5 years after being removed from the reactor,
- Half the fission/activation product hydrogen (including ^3H) migrated and became trapped in the Zircaloy® cladding, leaving 50% of the hydrogen in the fuel matrix.

Those volatile elements composed of more than one isotope were quantified on the basis of the number of moles of the element. For example, the moles of hydrogen (H_2) includes the gram-atoms of ^1H , ^2H , and ^3H , and while the radioactivity arises only from the ^3H , it is assigned to the gross fuel-borne H_2 . Table 2 summarizes the expected amount and activity of several elements of interest contained in 500 g of fuel matrix (i.e., without cladding). The chlorine and bromine are included because, as a first approximation, they will behave like the iodine and will consume part of the capacity of the iodine sorbent.

Table 2: Selected elements in 500 g of used UO_2 fuel.

Elements	Amount	Units	Activity (Ci)
U	440.74	g	
H_2	4.78E-06	mol	3.85E-01
C	3.64E-03	mol	3.26E-04
I_2	5.29E-04	mol	1.83E-05
Cl_2	3.29E-05	mol	1.97E-05
Br_2	9.15E-05	mol	
Kr	3.10E-03	mol	5.11E+00
Xe	2.90E-02	mol	

Table 3 shows the concentrations that would be present in a 5 L recirculation loop at the conclusion of the oxidation if no radionuclides were removed from the gas phase during the course of the oxidation.

Tritium (as part of the total hydrogen isotopes present) is the second-largest contributor to the radioactivity released (with the Kr isotopes being the largest contributor), but may be present at a maximum concentration of only ~ 25 ppm. Iodine may be present at a maximum concentration of ~2,700 ppm. The low concentration of tritium (hydrogen) suggests that allowing the tritium to build up to the maximum concentration within the loop may be necessary to improve overall recovery; it would be recovered from the gas at the conclusion of the oxidation. The iodine is present at much higher concentrations and thus online removal during oxidation will be practicable.

Table 3: Concentration of gases in a totally enclosed recirculation loop

Species	Concentration (mol/mol)*	Activity (Ci)
O ₂ + NO ₂	0.8127	
H ₂ O†	2.46E-05	3.85E-01
CO ₂	1.87E-02	3.26E-04
I ₂	2.72E-03	1.83E-05
Cl ₂	1.69E-04	1.97E-05
Br ₂	4.71E-04	
Kr	1.59E-02	5.11E+00
Xe	1.49E-01	
TOTAL	1.000000	
<p><i>*Total moles in the loop are calculated on the basis of a temperature of 40°C and 1 atm pressure. At elevated temperatures, the decrease in the total will be in the O₂+NO₂ portion, implying that the concentration of the fission product gases, in these units, will be larger.</i></p>		
<p><i>† All the hydrogen isotopes are shown as existing in water. The temperature-dependent equilibrium between water and NO_x results in distribution of the fuel-borne hydrogen between H₂O and HNO₃. If the hydrogen were in HNO₃ exclusively, the number of moles of HNO₃ would be twice that of H₂O.</i></p>		

2.3 Speciation of the tritium to be removed

A previous report (DeLCul et al. 2014) discussed the potential speciation of tritium within the NO₂ recirculation loop. Calculations with the HSC software (Outotec 2014) show that tritium will be present primarily as HNO₃ at temperatures below 50°C and that it will be present primarily as H₂O at temperatures above 250°C (Figure 2). Thus, in the design of the APTOG treatment system, two treatment options can be considered: (1) removal of HNO₃ at low temperature, and (2) removal of H₂O at high temperature.

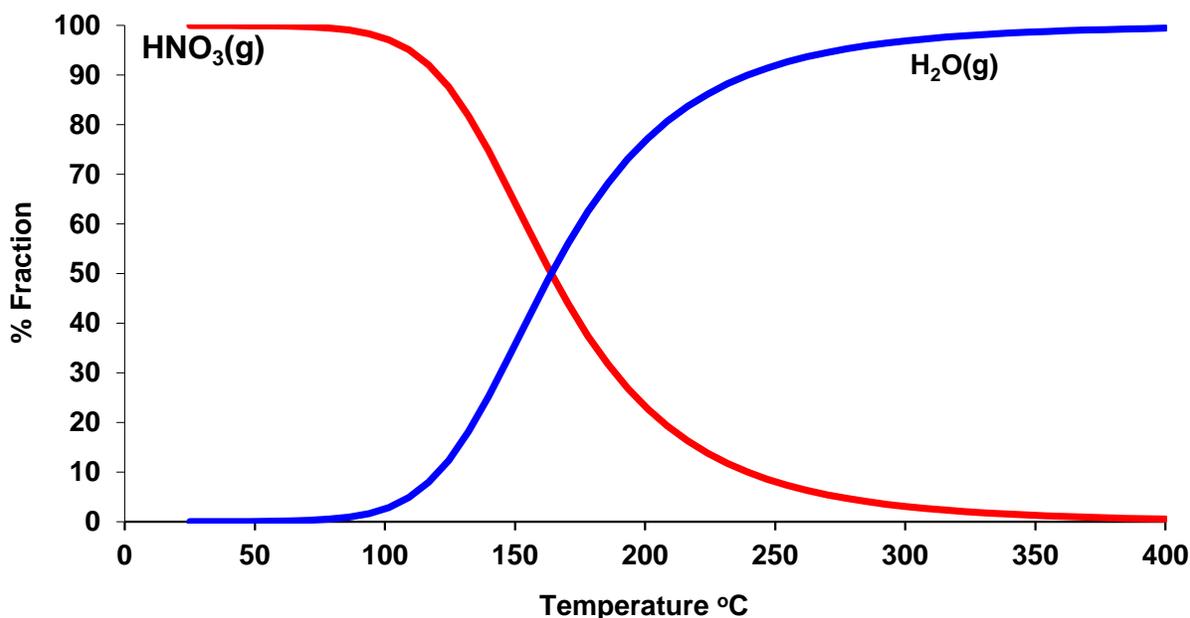


Figure 2: Relative distribution of hydrogen in the gaseous phases in the presence of $\text{NO}_2/\text{N}_2\text{O}_4/\text{O}_2$ mixtures (DeICul et al. 2014)

Each of these situations poses technical challenges, and a decision on the process gas treatment temperature necessitates the considerations of these challenges. As an example, adsorption of water is a well-studied process, but the primary candidate sorbent, the 3A molecular sieve (3AMS), is not expected to adsorb at high temperatures (i.e., sorption capacity may be extremely small). Adsorption of nitric acid is less studied and could be limited by competition with NO_2 adsorption.

3. Potential Sorbents for Utilization in Volatile Radionuclide Trapping

The design of an experimental system to demonstrate the removal of tritium and iodine from the off-gas of the TPT process needs to meet the following criteria: (1) recover the tritium and iodine separately from one another (i.e., minimize coadsorption); (2) achieve decontamination factors of 100 and 1,000 for tritium and iodine, respectively; and (3) utilize methods likely to be implemented in a full-scale plant design. Additionally, it is desirable to close the material balance on tritium and iodine. Because the selected process must be implemented at very small scale, the potential exists that a process suitable for a full-scale plant may be impractical at the experimental scale. Thus it may be necessary to demonstrate specific processes on a small scale and then to use alternative methods to obtain sufficient data to close the material balances.

3.1 Iodine sorbents

Previous work on iodine sequestration at ORNL has focused on the use of reduced silver mordenite (Ag^0Z) as the candidate iodine sorbent. However, Ag^0Z adsorption of iodine in the presence of high concentrations of NO_2 has been shown to be reduced by 90%, or more compared with NO_2 -free iodine adsorption (Jubin et al. 2013). Reductions in capacity may be caused by oxidation of the silver metal.

Other iodine sorbents, such as other silver zeolites, lead-exchanged zeolites, and activated charcoal were also considered impractical because of oxidation of the active metal and compatibility concerns. Silver nitrate is unreactive with NO_2 . Thus dry silver-nitrate impregnated alumina (AgA) was determined to be the most appropriate sorbent for iodine removal from the ATPOG.

Work performed in Japan (Hattori et al. 1984, Fukasawa et al. 1994) has demonstrated that AgA has an iodine adsorption capacity of 10 wt % iodine for a 10 wt % silver sorbent sample and that AgA is robust to the presence of NO_2 . Research performed at ORNL has demonstrated that the capacity reduction of iodine when exposed to a high- NO_2 environment for 1 week is 15% (Jordan et al. 2015). The following design assumed a once-through treatment case where iodine builds up in the system, reaches the final concentration (2,720 ppmv), and is treated after the cycle is complete. If the iodine were removed on line, the operating concentration would be lower and the system design could still be expected to result in quantitative iodine removal. Data from Fukasawa et al. (1994) suggest that decontamination factors (DFs) for iodine on AgA at 750 ppmv approach 10,000, much higher than the required DF of 1,000 in this design.

General estimates of the bed size necessary for iodine adsorption system can be obtained in similar fashion to that of Jubin et al. (2016). A sorbent is chosen with specific values of iodine adsorption capacity and bulk density, and the system variables such as gas flowrate and iodine concentration are specified. In this case, the sorbent would be AgA with a nominal iodine adsorption capacity of 5 wt %, based on the performance of laboratory tests under similar conditions. In order to build in a margin, one could conservatively halve the iodine adsorption capacity to 2.5 wt %. The assumed density is 800 kg. The iodine concentration is assumed to be 2,720 ppmv, and chlorine and bromine are present at 169 and 471 ppmv, respectively; these numbers were calculated at a temperature of 40°C and a pressure of 1 atm. In a total of 5 L of recirculating gas, this results in 0.1343 g of iodine, 2.332E-3 g of chlorine, and 1.464E-2 g of bromine to be adsorbed. The recirculating gas velocity is chosen to be 10 m/min. For this exercise, the DF was chosen to be 1,000. Thus the amount of iodine to be captured is 0.1342 g, with 2.329E-3g of chlorine and 1.463E-2 g of bromine being captured simultaneously.

These conditions result in a column diameter of 1.60 cm (0.628 in) and a sorbent inventory (at the previously mentioned 2.5 wt % capture capacity) of 6.05 g. At a density of 800 kg/m³, the column must be at least 3.78 cm long. However, the length of the mass transfer zone likely exceeds this column length; Fukasawa et al. (1994) reported that the DF for I_2 on AgA at low NO_x and water concentrations exceeds 1,000 at 5 cm, but given the high NO_2 concentration present, the length of the mass transfer zone is expected to increase. Thus, a conservative assumption is that, in the final column design, the length of the mass transfer zone is 10 cm, resulting in final column dimensions of 1.60 cm diameter and 10 cm length. This column will be tested to assess its iodine removal efficiency prior to installation in the hot-cell system.

3.2 Tritium sorbents

The composition of the ATPOG and the distribution of tritium into either HNO_3 or H_2O as shown by Figure 2 present a challenge when selecting potential sorbents. Common sorbents for H_2O are designed to operate at temperatures lower than 250°C, and there is very little information regarding the removal of HNO_3 from an NO_2 -bearing stream. The results of a literature review on this topic are presented here along with generalized descriptions of scoping tests to be completed.

3.2.1 Potential solid sorbents for nitric acid at 40°C

Recovery of HNO_3 , and, in this instance, tritiated nitric acid has not been the subject of prior off-gas treatment studies by the Off-Gas Sigma Team. Without benefit of prior studies, it became necessary to

review the literature and to identify methods that might be used successfully to recover nitric acid vapors from the ATPOG off-gas.

3.2.1.1 Nylon

Commercially available nylon filters have been used for the atmospheric sampling of HNO_3 (Gregory, et al. 1990, Fehsenfeld et al. 1998). HNO_3 is present in the atmosphere in parts-per-billion to parts-per-trillion concentrations, and a literature review shows that nylon filter material is one of few sorbents that have been demonstrated to effectively remove HNO_3 in the concentration ranges applicable to the ATPOG. In atmospheric applications, nylon (Nylasorb) has been found to have HNO_3 loadings in the range of $0.1 \mu\text{g}/\text{cm}^2$ to $2.2 \mu\text{g}/\text{cm}^2$ (Goldan et al. 1983).

In review of the literature discussing atmospheric HNO_3 sampling and quantification, it became clear that a major concern in any sampling or sorbent system is the loss of HNO_3 to the materials of construction (Neuman et al. 1999). This is unsurprising, given the reactivity of the compound. The study by Neuman et al. indicates that glass, stainless steel, aluminum, silica-coated and silica-based materials, and nylon materials of construction all removed more than 85% of the HNO_3 from a stream containing HNO_3 at a concentration of 5.6 ppbv. The material found to be most inert with respect to nitric acid adsorption was PFA Teflon. This finding should be used to govern materials selection for the ATPOG system.

An additional consideration in the use of nylon to remove HNO_3 is the high concentrations of NO_2 in the gas stream. It is unclear how nylon could be affected by high concentrations of NO_2 . Jellinek, et al. (1973) demonstrated that the scission of the polymeric structure is dependent on the diffusion of NO_2 into the polymer itself, but that study does not provide insight into the practical lifetimes of nylon film in a 75% NO_2 stream. It is also unknown how the presence of high concentrations of NO_2 could affect the adsorption of HNO_3 on the nylon filter material.

Initial testing will evaluate the sorption capacity of Nylasorb for HNO_3 in a 75% NO_2 stream at 40°C . Nylon is moderately stable when exposed to a radiation field, but prior to any implementation in a hot cell test, a review of the available literature on nylon radiolysis should be performed to evaluate practical concerns and safety concerns. If the tests demonstrate that nylon is superior to the other tritiated HNO_3 capture methods, future testing could examine the impact of temperature, NO_2 concentration, and exposure time on the adsorption of HNO_3 by nylon materials.

3.2.1.2 Silica gel

The amount of data available on the adsorption of HNO_3 by silica gel is limited. In the evaluation of materials of construction appropriate for HNO_3 sampling, Neuman et al. (1999), found that silica-coated and silica-based materials removed 85% of the HNO_3 from a stream having an HNO_3 concentration of 5.6 ppbv. That reference was also used in the previous section of this document to identify nylon as a potential HNO_3 adsorbent.

DeICul et al. (2014) documented some limited testing that was performed on the adsorption of HNO_3 by silica gel. The testing was performed by introducing 99% fuming HNO_3 into the simulated ATPOG test loop and operating the silica gel trap at ambient temperature. The HNO_3 concentration was monitored by Fourier transform infrared spectroscopy (FTIR), and no HNO_3 was observed at the trap. The detection limit of the FTIR measurement method was not reported, and it is not known whether the removal of HNO_3 by silica gel is dependent upon the concentration of HNO_3 in the gas stream.

Although limited in scope, the results of the two studies indicate that silica gel is a promising sorbent for HNO_3 in an NO_2 -bearing stream. Scoping tests will investigate HNO_3 removal at 40°C by a silica gel trap in a simulated ATPOG stream.

3.2.1.3 5A Molecular Sieve

No information was found on the separation of gas-phase nitric acid from NO_x gases. There are references on the recovery of NO_2 from the off-gases of nitric acid plants using zeolite-based molecular sieves (Rosenberg 1976, Klopp et al. 1983). Molecular sieves 4A, 5A and 13X possess aperture sizes sufficiently large to capture NO_2 (Sigma-Aldrich 2017). Nitric oxide (NO) is also captured, but in the presence of O_2 it is rapidly converted to NO_2 ; the high surface sorbent acts as a catalyst. It is probable that HNO_3 is captured in the molecular sieves having the larger aperture openings, or in the presence of water the co-adsorption of water will result in production of HNO_3 . In summary, there seems to be little likelihood that a molecular sieve is available to selectively remove HNO_3 from concentrated NO_x streams, but scoping studies should be conducted to confirm this conclusion.

3.2.2 Potential solid sorbents for H_2O at 250°C

As shown in Fig. 2, gas temperatures of around 250°C or higher are required for near complete dissociation of nitric acid to water and nitrogen oxides. Molecular sieve type 3A has been tested extensively for sorption of water in the presence of acidic gases and in the presence of iodine. However, the water sorption phase of these tests was conducted at temperatures of 40°C or less. Temperatures up to 275°C were used to regenerate the 3AMS during a desorption cycle (Spencer et al. 2014). Data on the sorption isotherms of water from lean gas streams at temperatures above 100°C do exist. Based on desorption studies, the 3AMS does have a low capacity for water at 150°C . It is possible that continuous H_2O removal by a 3AMS sorbent held at an elevated temperature could push the HNO_3 - H_2O equilibrium such that additional acid would dissociate and result in additional water that could be removed. Alternatively, the acid-bearing stream could be heated to a high temperature to cause the dissociation to water, and if the cooling of the gas can be completed much faster than the recombination to form nitric acid, then the 3AMS could remove the water. To the knowledge of the authors, those approaches have not been tried.

The studies by DelCul et al. (2014) indicate that silica gel could be a sorbent for water at elevated temperatures. Unlike the 3AMS, which is relatively selective, silica gel does not have a well-defined aperture size and could adsorb many different off-gas species. Initial scoping tests will assess the use of both silica gel and 3AMS to remove dilute concentrations of H_2O at a temperature where HNO_3 dissociation should be substantial.

3.2.3 Use of an aqueous scrubber at 40°C

Scrubbing the gas stream with water captures both nitric acid and water vapor. The nitric acid fumes preferentially distribute to the liquid phase, and the tritium from the acid mixes isotopically with the hydrogen in the water. Similarly, the water vapor mixes isotopically with the scrubbing water. In both cases, the vapor pressure of tritiated nitric acid and tritiated water is the only escape from the solution, and because of the significant dilution with ordinary water, the vapor fraction consisting of tritiated species is extremely low. Aqueous scrubbing does have the side effect of absorbing NO_2 (which will convert to nitric acid in solution) and may offer efficiencies that solid sorbents do not. Such an approach is not ideal, but it may be necessary. The aqueous scrubber will be tested if solid sorbents are not shown to be effective at removing either HNO_3 or H_2O . The extent of iodine capture must also be determined.

4. System Design and Conclusions

As was discussed in Section 2.2, the dilute tritium concentrations expected within the advanced TPT loop led to a decision to remove tritium at the conclusion of testing from a bleed stream. Iodine removal will be conducted within the recirculation loop. A schematic depicting this treatment process concept is shown in Figure 3. This is not a detailed process instrumentation diagram and does not show all inlet streams, valves, and associated equipment. Following tritium treatment, the gas bleed stream will be passed through an NO₂ aqueous scrubber. The beds will be analyzed for tritium to assess the effectiveness of the initial treatment bed. There are additional beds built into the design that could remove the noble gases (Kr and Xe), but it is unlikely that they will be utilized. This design is conceptual and will be adjusted if needed based upon results from the scoping studies described in this report.

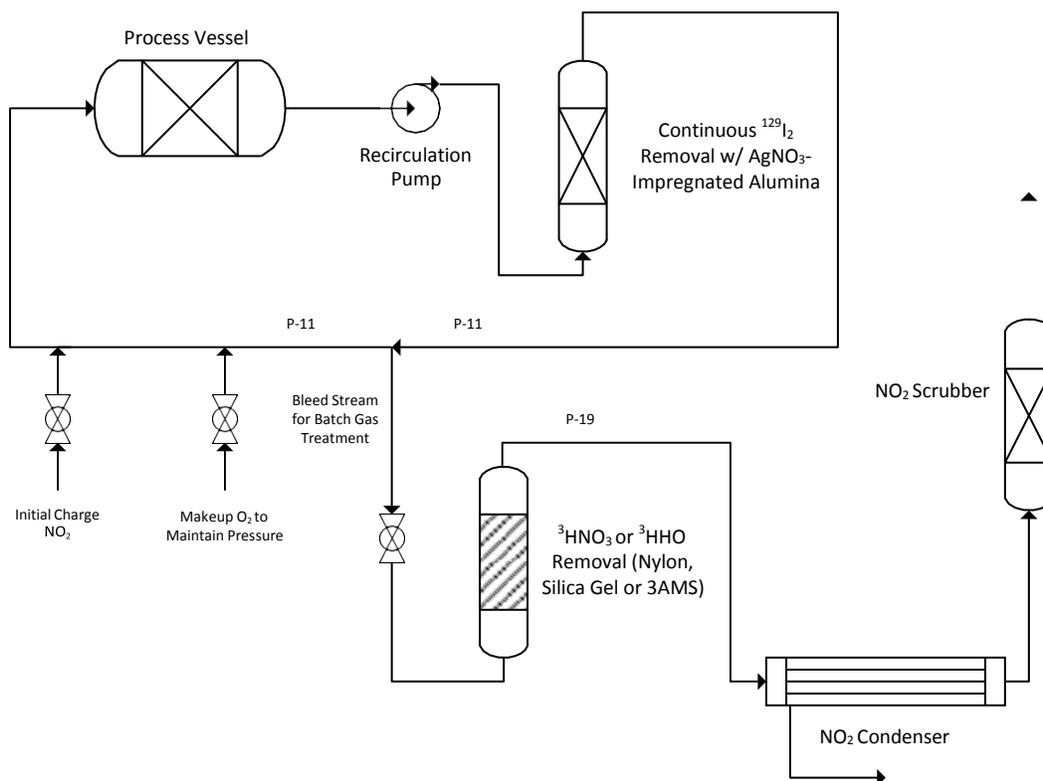


Figure 3: Process Design for the ATPOG Stream

One important aspect of the off-gas treatment system described here will be the analytical methodology used to determine iodine and tritium on each sorbent. Both components are easily analyzed, but special care should be taken to ensure that the sampling protocol and detection limits are such that the mass balance of the iodine can be effectively closed. Closure of the iodine mass balance will provide confirmation of the ability of advanced TPT to quantitatively remove iodine, potentially simplifying the remainder of a plant's off-gas treatment system.

The scoping studies described in this report are intended for completion in FY17. The results will be used to identify the most promising tritium removal methods for use in the treatment of the ATPOG. Additional work to more fully characterize the sorbent technology may be necessary prior to a detailed design of the hot cell system. Any additional R&D will be completed on a time line that will facilitate incorporation of the removal technologies into the planned advanced TPT demonstration in FY18.

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