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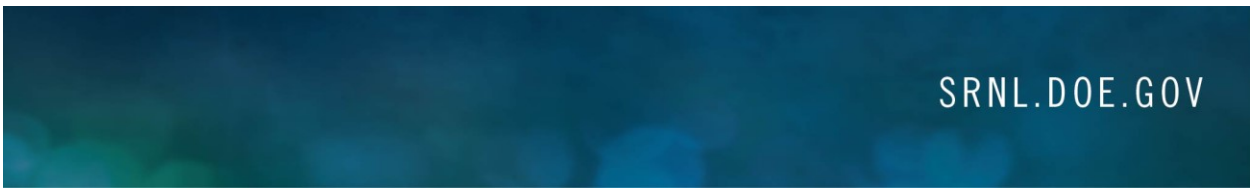
SRNL-STI-2020-00258, Revision 0



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EXECUTIVE SUMMARY

Tritium confinement is performed using different barriers to minimize releases to the environment. Primary confinement is usually performed by process piping and components, secondary confinement typically by inerted gloveboxes connected to a continuously operating tritium stripper system. Some facility designs employ tertiary tritium confinement by using process room confinement with a tritium stripper system activated after an accident to further mitigate tritium releases to the environment.

Secondary confinement of some tritium systems such as radiation-hardened or shielded-cell enclosures are not easily achieved using designs for inerted glovebox. These enclosures can be challenging to seal for secondary tritium confinement due to heating, ventilation, and air conditioning (HVAC) needs for temperature control, as well as feedthroughs for equipment and instrumentation, are potential pathways for tritium leaks or loses. Additional tritium leak paths can be created in secondary confinement enclosures due to a Design Basis Accident (DBA) seismic event. These new, larger tritium leak rates from the DBA event are usually not part of the stripper system design basis so all tritium released to the secondary confinement enclosure is assumed released to the environment.

Detritiation strategies for shielded enclosures and/or gloveboxes with significant leak rates are necessary to minimize off-site radiological dose consequences. To address this, the relationship between the confinement system leak rate and stripper system (recirculating) flow rate was evaluated to meet prescribed maximum allowable environmental tritium emissions from the event. The simple analysis described assumes a constant leak rate from the confinement system (i.e. shielded enclosure or glovebox) while a recirculating stripper system strips tritium from the system– a competition between tritium release and tritium recovery. At a high level, the resulting expression summarizes the relationship between system leak rate (F_L) and stripper flow rate (F_S) relative to allowable tritium release (Q_A) and initial tritium release (Q_0):

$$\frac{F_L}{F_S} \approx \frac{Q_A}{Q_0}$$

This report derives the relationship between these parameters, examines the impact of finite stripping times followed by purging of the stripped volume. The analysis provides example results for up to 30 gram tritium releases: the maximum tritium inventory of a Hazard Category III (Department of Energy) Nuclear Facility.

The detritiation model presented represents a high-level analysis of tritium recovery versus losses for "leaky" confinement enclosures such as shielded cells after large tritium releases. Key parameters for doing the analyses are the system leak rate, stripper flow rate, initial tritium release, and allowable tritium release values. The analyses show a proportional decrease in releases with reduction in initial tritium release but a non-linear increase in tritium recovery with increased stripper flow rate or reduced leak-rate. The analyses also apply to glovebox confinement systems which could have significant increases in leak rates after a DBA. The analysis recognizes but does not include tritium absorption followed by re-emission from the walls of the confinement volume – an analysis which could be pursued in future studies.

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LIST OF ABBREVIATIONS

AMSB	Ambient temperature molecular sieve bed
C	Concentration of tritium (μCi/cc)
cc	Cubic centimeter (cm^3)
CFM	Cubic feet per minute (ft^3/min)
Ci	Curie
C_{In}	Concentration of tritium entering the stripper (μCi/cc)
C_{Out}	Concentration of tritium leaving the stripper (μCi/cc)
DAC	Derived Air Concentration
DAC-HT	Derived Air Concentration for elemental tritium, $2x10^{-1}$ μCi/cc
DAC-HTO	Derived Air Concentration for tritium oxide, $2x10^{-5}$ μCi/cc
DBA	Design Basis Accident
DF	Decontamination factor, initial concentration divided by concentration
DOE	Department of Energy
ε	Stripper efficiency
F_L	Leak flow rate (ft^3/min)
F_S	Stripper flow rate (ft^3/min)
g	Gram
HVAC	Heating, ventilation, and air conditioning
L	Liter
LOC	Limiting Oxidant Concentration
LR	Leak Ratio = F_L / F_S
MetBel	Metal bellows pump
MS	Molecular sieve
NRC	Nuclear Regulatory Commission
Q	Quantity of tritium (Ci or g)
R_L	Tritium release leaked to the environment
R_S	Tritium release captured by stripper system
R_T	Tritium release total – total loss to environment = $R_L + R_V$
R_V	Tritium release vented to the environment after stripping is stopped
t	Time (min)
τ	Time constant (min)
τ_L	Time constant for leak = V / F_L (min)
τ_S	Time constant for stripper = V / (ε F_S) (min)
τ_T	Total time constant = V / (ε $F_S + F_L$) (min)
V	Void volume stripped (ft^3 or L)

w.r.t.	With-respect-to

Additional Subscripts

min	Minimum value
max	Maximum value
0	Initial (time zero) value/reading/quantity
A	Allowable value/reading/quantity

1.0 Introduction

In applications where tritium is handled, tritium confinement is performed using different barriers to minimize releases to the environment. For gaseous (elemental) and liquid (oxide) tritium, process piping and components provide the primary confinement function. Air flow hoods containing the processing systems can dilute and carry tritium away to minimize personnel exposure when accessing the process systems but do not mitigate environmental releases without exhaust diversion, collection, and treatment systems.

Secondary tritium confinement is typically provided by gloveboxes or modules (gloveboxes with access panels for installation of tritium systems, but no glove ports); and is typically connected to a tritium stripper system. The tritium-containing gloveboxes are often inerted with a non-flammable gas (nitrogen, argon, helium) to suppress oxygen levels below the Limiting Oxidant Concentration (LOC) to prevent deflagrations of the hydrogen isotopes. The inerting systems are also designed to control glovebox pressure and purging of the glovebox for oxygen control. Tritium recovery (stripper) systems remove tritium from the atmosphere of the secondary confinement systems for recirculation or discharge.

Some facility designs employ tertiary confinement of tritium by using room or building confinement with tritium stripper systems to prevent (minimize) release of the tritium. Room volumes are many times larger than the volume of secondary confinement barriers and require either very large stripper systems or very long stripping times for tritium recovery to minimize airborne emissions. Typical tritium stripper systems employ catalytic oxidation of tritium followed by desiccant drying, typically ambient temperature molecular sieve (MS) beds (AMSBs). The oxidized tritium recovered is typically diluted with protiated water removed from the process room air (permeated into the glovebox), thus increasing the volume of tritiated water requiring disposition.

Secondary confinement of some tritium systems is not easily achieved by an inerted glovebox or confinement modules. For these circumstances, room strippers, typically used as a tertiary confinement option, are relied upon to provide the secondary confinement function. These circumstances sometimes require tritium confinement in radiation hardened or shielded cell enclosures which can be challenging to seal for secondary tritium confinement. Heating, ventilation, and air conditioning (HVAC) needs for controlling the temperature of shielded cells is another pathway for loss of tritium from the secondary confinement structure.

Detritiation of the shielded enclosures, gloveboxes, and general tritium process work area using tritium stripper systems is necessary if tritium contamination is detected. Alternately, the tritium source term could be reduced. These strategies are necessary to minimize tritium contamination and off-site radiological dose due to tritium leak paths. In order to address tritium release scenarios from a shielded enclosure or the glovebox following a DBA, a relationship between the leak rate and stripper system flow rate (recirculating) is evaluated. This report examines the relationship between stripper system flow rate and leak rate from a shielded cell type enclosure or glovebox to meet prescribed maximum allowable tritium emissions from the event.

2.0 Background

2.1 Methodology for Sizing the Tritium Stripper System

When designing tritium stripper systems for glovebox or module confinement systems, design input parameters usually start with a DBA tritium release into the confinement system volume. Next, either a stripping time is specified to achieve some reduced tritium concentration in the confinement volume, or a stripper flow rate is supplied based on flow rates of the pumps or blower to be used in the system. Stripper

technology (i.e. material, method) selection usually follows next and usually makes some assumption of stripper efficiency or stripper outlet tritium concentration. These design inputs then allow comparison of different technologies to perform the required stripper function.

Maximum allowable leak rates from the secondary confinement enclosure to the facility tritium release (discharge) point are usually not part of the stripper design basis. The secondary enclosure leak-tightness is usually defined for worker protection rather than specified by facility release considerations after a DBA such as an earthquake. This report will examine the relationship between stripper flow rate and the leak rate from a shielded cell to define design criteria needed to limit tritium emissions to the public. The analysis also applies to glovebox confinement systems which are expected to have low leak rates which could increase significantly after a DBA.

2.2 Tritium Stripping Conditions

For this study, the dimensions of a shielded cell to be stripped will be a 12 foot by 12 foot by 20 foot (2,880 ft^3, 81,550 L) enclosure with different fractions of the cell void space occupied by equipment. Larger void spaces (less equipment volume) generally correlates with lower initial tritium concentration for a defined DBA release quantity. The assumed void space in the cell will vary between 25 to 75% and releases analyzed of nominal stripped volumes between 720 ft^3 and 2,160 ft^3.

The Department of Energy (DOE) Standard "Tritium Handling and Safe Storage"[1] defines facility hazard categories based on tritium inventory. A Hazard Category II Nuclear Facility has greater than 30 g tritium, A Hazard Category III Nuclear Facility has between 1.6 g and 30 g tritium. Non-Nuclear Radiological Facilities have less than 1.6 g tritium; Hazard Category I Nuclear Facilities are generally limited to nuclear reactors. This study will examine tritium releases for Hazard Category III Nuclear Facilities up to 30 g tritium. A 1.6 g release in a 2,160 ft^3 void volume would give an initial tritium concentration of 252 μCi/cc and a 30 g release into a 720 ft^3 void volume would produce an initial tritium concentration of 14,151 μCi/cc.

Many publications have assessed tritium stripping of enclosed chambers and only a few will be referenced here.[2,3,4,5] Table 2-1 summarizes some of the parameters from tritium stripper references. The studies are listed in increasing order of volume stripped by a recirculating stripper system. The concentration of tritium in the initial release is shown in the last column. The decontamination factor (*DF*) is the ratio of the initial tritium release concentration divided by the final tritium concentration. The *DF* of a single-stage tritium stripper is typically limited to around 1,000.[3,4] This study focuses on expected performance characteristics of a single-stage, recirculating tritium stripper system, and identifies the nominal stripper flow required to not exceed the maximum tritium discharge.

Table 2-1 – Previous Tritium Stripping Studies

Study	Nominal Stripped Volume (L) [ft^3]	Nominal Stripper Flow (L/min) [CFM]	Initial Tritium Conc. (μCi/cc)
1992 Shmayda et al.[2]	14.4[a] [0.508]	0.75 [0.026]	$1.2x10^{-4}$ to 6.8
1995 Klein and Wermer[3]	620 [21.9]	~ 2 to 9 [0.071 to 0.318]	~ 1 to 10
2001 Kobayashi et al.[4]	11,960[b] [422.3]	833 [29.4[c]]	$5.9x10^{-3}$
1995 Heung[5]	24,000 [847]	2,833 [100[d]]	~ 4,000

Study	Nominal Stripped Volume (L) [ft^3]	Nominal Stripper Flow (L/min) [CFM]	Initial Tritium Conc. (µCi/cc)
This Study	20,400 to 61,200 [720 to 2,160]	To Be Determined	4,717 to 14,151[e]

[a]From Ref. 2: Table 2 by multiplying volumetric flow rate times circulation time constant.
[b]From Ref. 4: dimensions of 2.6 m by 2.0 m by 2.3 m.
[c]From Ref. 4: derived from 50 m^3/h.
[d]From Ref. 5: derived from 170 m^3/h.
[e]30 g tritium release values.

3.0 Tritium Stripping

3.1 Ideal Stripping Model

This section describes the idealized model (no tritium absorption or reactions) used to assess the performance of a tritium stripper system from a secondary confinement volume with a leak. The leak from the volume contributes directly to the amount of tritium released to the public and contributes to the public dose calculation. Stripping continues for a finite duration or until some defined criteria (e.g. tritium concentration in the volume) is met. Any residual tritium in the volume at the end of stripping is vented/exhausted from the volume and contributes to the public dose calculation.

3.1.1 Cell Mass Balance

The initial concentration of tritium in the cell (C_0) is calculated by dividing the quantity of the tritium released at time zero, (Q_0), divided by the void volume of the cell (V):

$$C_0 = \frac{Q_0}{V} \quad \text{(Eq. 1)}$$

A mass balance on the void volume V generates the differential equation

$$\frac{d[VC]}{dt} = F_S C_{Out} - F_S C_{In} - F_L C = -(\varepsilon F_S + F_L)C \quad \text{(Eq. 2)}$$

where C is the tritium concentration in the cell as a function of time (t), C_{In} and C_{Out} are the tritium concentrations at the inlet and outlet of the stripper, respectively, F_S is the stripper flow rate, F_L is the leak flow rate, and ε is the stripper efficiency defined by

$$\varepsilon = 1 - \frac{C_{Out}}{C_{In}} \quad \text{(Eq. 3)}$$

where C_{In} is assumed to be the same as the concentration in the void volume (well mixed assumption). The solution to Equation 2 is given by

$$C = C_0 e^{-\frac{t}{\tau_T}} \quad \text{(Eq. 4)}$$

where C_0 is the concentration of tritium at time zero (Equation 1). τ_T is the total time constant for the cell, derived from Equation 2:

$$\frac{1}{\tau_T} = \frac{1}{\tau_S} + \frac{1}{\tau_L} = \frac{\varepsilon F_S}{V} + \frac{F_L}{V} = \frac{(\varepsilon F_S + F_L)}{V} \quad \text{(Eq. 5)}$$

$$\tau_T = \frac{V}{\varepsilon F_S + F_L} = \frac{V}{\varepsilon F_S}\left(\frac{1}{1+\frac{LR}{\varepsilon}}\right) = \tau_S\left(\frac{1}{1+\frac{LR}{\varepsilon}}\right) \quad \text{(Eq. 6)}$$

where τ_S and τ_L are the time constants for the stripper flow rate and leak rate, respectively. The Leak Ratio (LR) is defined as the ratio between the leak flow rate and stripper flow rate:

$$LR = \frac{F_L}{F_S} \quad \text{(Eq. 7)}$$

The initial tritium released at time zero ($t = 0$) is distributed between three terms:

$$Q_0 = R_S + R_L + R_V \quad \text{(Eq. 8)}$$

where R_S is the quantity of tritium released captured by the stripper system, R_L is the tritium released through leaking, and R_V is the tritium released through venting at the end of the event when stripping is stopped, and the volume is purged. Purging is expected to be done at the end of stripping operations to reduce the tritium concentration below the Derived Air Concentration (DAC) to allow personnel access to the area (as applicable). The DAC for elemental tritium, DAC-HT, is $2\text{x}10^{-1}$ µCi/cc and the DAC for tritium oxide, DAC-HTO, is $2\text{x}10^{-5}$ µCi/cc.[1]

3.1.2 Tritium Captured by Stripper (R_S)

The amount of tritium captured by the stripper (R_S), is obtained by integrating the amount of tritium entering the stripper less the integrated quantity of tritium exiting the stripper:

$$R_S = \int_0^t (F_S C)dt - \int_0^t [F_S C(1-\varepsilon)]dt$$

$$R_S = F_S \varepsilon C_0 \tau_T \left[1 - e^{-\frac{t}{\tau_T}}\right] = Q_0\left(\frac{\varepsilon F_S}{\varepsilon F_S + F_L}\right)\left[1 - e^{-\frac{t}{\tau_T}}\right] \quad \text{(Eq. 9)}$$

3.1.3 Tritium Release through Leak (R_L)

The amount of tritium lost through leakage (R_L), is obtained by integrating the amount of tritium leaving the cell or glovebox through the leak:

$$R_L = \int_0^t (F_L C)dt = F_L C_0 \tau_T \left[1 - e^{-\frac{t}{\tau_T}}\right] = Q_0\left(\frac{F_L}{\varepsilon F_S + F_L}\right)\left[1 - e^{-\frac{t}{\tau_T}}\right] \quad \text{(Eq. 10)}$$

3.1.4 Tritium Release through Venting (R_V)

At the end of the event when stripping is stopped, the residual tritium will be released to the environment by venting (purging) the cell or glovebox. The amount of tritium released from venting (R_V) is given as the product of the void volume times the concentration of tritium:

$$R_V = VC = VC_0 e^{-\frac{t}{\tau_T}} = Q_0 e^{-\frac{t}{\tau_T}} \quad \text{(Eq. 11)}$$

3.1.5 Total Tritium Release (R_T)

The total tritium released to the environment (R_T) is the summation of both R_L and R_V (Equation 10 and Equation 11):

$$R_T = R_L + R_V = Q_O \left[\frac{F_L}{\varepsilon F_S + F_L} + \left(\frac{\varepsilon F_S}{\varepsilon F_S + F_L} \right) e^{-\frac{t}{\tau_T}} \right] \quad \text{(Eq. 12)}$$

R_T calculated using Equation 12 at time zero reduces to Q_0 – the amount of the initial tritium release which would be stacked at time equal to zero. R_T calculated for no stripper flow ($F_S = 0$) also reduces to Q_0 due to all of the initial release being lost through the leak. R_T calculated for no leak flow ($F_L = 0$) reduces to

$$\lim_{F_L \to 0} R_T = Q_O e^{-\frac{t}{\tau_S}} \quad \text{(Eq. 13)}$$

which is Equation 11 with τ_T reduced to τ_S since τ_L is zero. This is the amount of tritium vented after tritium stripping is stopped at time t.

R_T calculated using Equation 12 as time goes to infinity reduces to the minimum amount of tritium released, $R_{T,min}$, since no tritium is released from venting:

$$R_{T,min} = \lim_{t \to \infty} R_T = \frac{Q_0 F_L}{(\varepsilon F_S + F_L)} = \frac{Q_0}{\left(1 + {}^{\varepsilon}/_{LR}\right)} \quad \text{(Eq. 14)}$$

Equation 14 establishes a clear relationship between Q_0, F_S, F_L, and to a lesser extent, ε. $R_{T,\,min}$ must be less than the maximum allowable release to the environment (Q_A), thus Equation 14 can be used to define the maximum leak rate:

$$R_{T,min} = \frac{Q_0 F_L}{(\varepsilon F_S + F_L)} = \frac{Q_0}{\left(1 + {}^{\varepsilon}/_{LR}\right)} \leq Q_A \quad \text{(Eq. 15)}$$

$$F_L \leq F_{L,max} = \varepsilon F_S \frac{Q_A}{(Q_0 - Q_A)} = \varepsilon F_S \frac{1}{\left({}^{Q_0}/_{Q_A} - 1\right)} \quad \text{(Eq. 16)}$$

Or in terms of leak ratio:

$$LR = \frac{F_L}{F_S} \leq \varepsilon \frac{Q_A}{(Q_0 - Q_A)} = \varepsilon \frac{1}{\left({}^{Q_0}/_{Q_A} - 1\right)} = \varepsilon \frac{1}{(DF_{min} - 1)} \quad \text{(Eq. 17)}$$

where DF is the decontamination factor for the cell and DF_{min} is the minimum required value of DF as defined by

$$DF = \frac{C_0}{C}, \quad DF_{min} = \frac{Q_0}{Q_A} \quad \text{(Eq. 18)}$$

Conversely, knowing the leak rate, Equation 15 can be used to define the minimum stripper flow rate:

$$F_S \geq F_{S,min} = F_L \frac{(Q_0 - Q_A)}{\varepsilon Q_A} = \frac{F_L}{\varepsilon}\left(\frac{Q_0}{Q_A} - 1\right) = \frac{F_L}{\varepsilon}(DF_{min} - 1) \qquad \text{(Eq. 19)}$$

Equation 19 offers a very simple relationship between the required stripper flow rate and the leak rate. For relatively large minimum *DF* values, and stripper efficiencies near unity, the ratio of the stripper flow rate to the leak flow rate must be greater than the minimum required decontamination factor:

$$F_S \geq F_{S,min} = \frac{F_L}{\varepsilon}(DF_{min} - 1) \approx F_L\, DF_{min} \quad \text{for } \varepsilon \approx 1,\ DF_{min} \gg 1 \qquad \text{(Eq. 20)}$$

3.2 Model Illustration

Figure 3-1 illustrates the tritium release analysis for a fabricated release scenario, with and without leaks, to graphically illustrate the previously derived expressions using normalized time and concentration. For a void volume of 720 ft^3, a stripper flow rate of 5 ft^3 per min. (F_S = 5 CFM) at 100% stripper efficiency (ε = 1.00), and a leak rate (F_L) of 1.50 CFM, the Leak Ratio is calculated to equal 0.3. The relatively large Leak Ratio value was chosen to create plots in the figure largely separated from one another to visually accentuate the difference in results with and without leaking. The normalized change in concentration as a function of normalized time (t/τ_S) with no leak is shown as the "Stripper Only" (solid green) line in the figure. The "Stripped + Leak" (dashed blue) line in the figure versus normalized time (t/τ_T) illustrates the greater than calculated/expected decrease in concentration due to tritium losses from the leak. The cross symbols on the "Stripper Only" line illustrate the expected number of residence times needed to reduce the initial concentration by a factor of 10^n, with n equal to one through six [note: n times ln(10) equals n times 2.303].

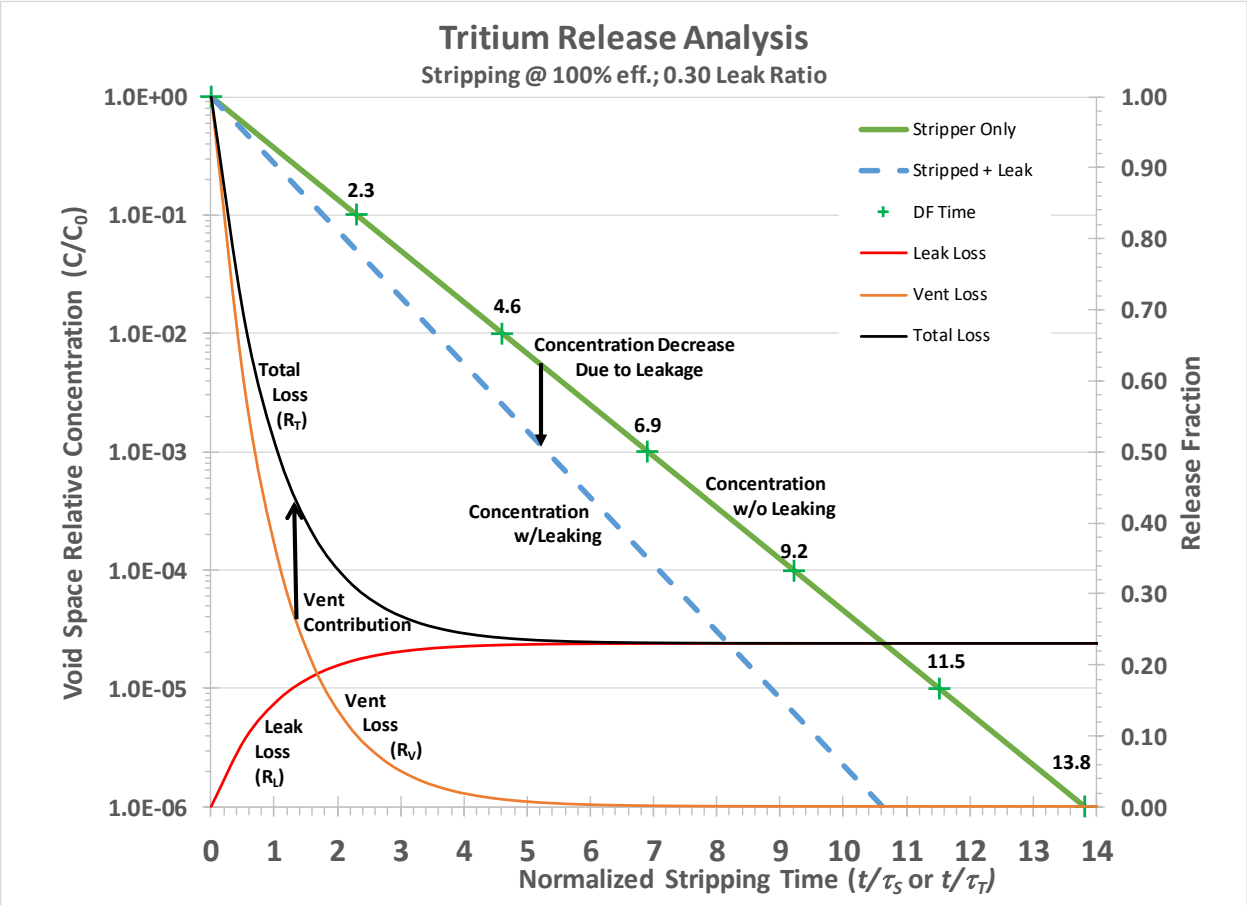

Figure 3-1 – Model Illustration Results

R_T, the sum of tritium lost through leakage plus venting, is shown as the "Total Loss" (black line) in Figure 3-1 as a fraction of the initial release on the right axis and is 37.5% at infinite time. R_L, tritium lost through the leak shown by the "Leak Loss" fraction (red line) in the figure while R_V, the tritium lost through venting is shown by the "Vent Loss" fraction (orange line) in the figure. As illustrated in the figure, the vent fraction decreases as the tritium is either captured by the stripper or lost to the surroundings through the leak.

4.0 Model Application

4.1 Worse-Case Analysis: Two Nominal Stripper Flow Rates

For volumes in this case study (shown in the last row of Table 2-1), it is estimated that an evacuation/ventilation flow up to 2.5 CFM (70.8 L/min) would be needed to maintain a shielded cell at a negative pressure w.r.t. the surroundings. Table 2-1 shows two previously used, relatively large stripper systems: 833 L/min (50 m^3/hr equals 29.4 CFM),[4] which will be rounded to 30 CFM for analysis, and 2,833 L/min (100 CFM).[5] For the accident scenario where Q_0 is 30 g of tritium – the upper limit of a Hazard Category III Nuclear Facility – is released and the ventilation damper is stuck open during the incident, Equation 14 calculates $R_{T,min}$ as 2.351 g and 0.7463 g for the 30 CFM and 100 CFM stripper, respectively, when using a stripper efficiency of 98% - an arbitrary value chosen as less than 100% to account for less than ideal stripping. The change in tritium concentration and the total tritium gram loss for these two scenarios are shown in Figure 4-1.

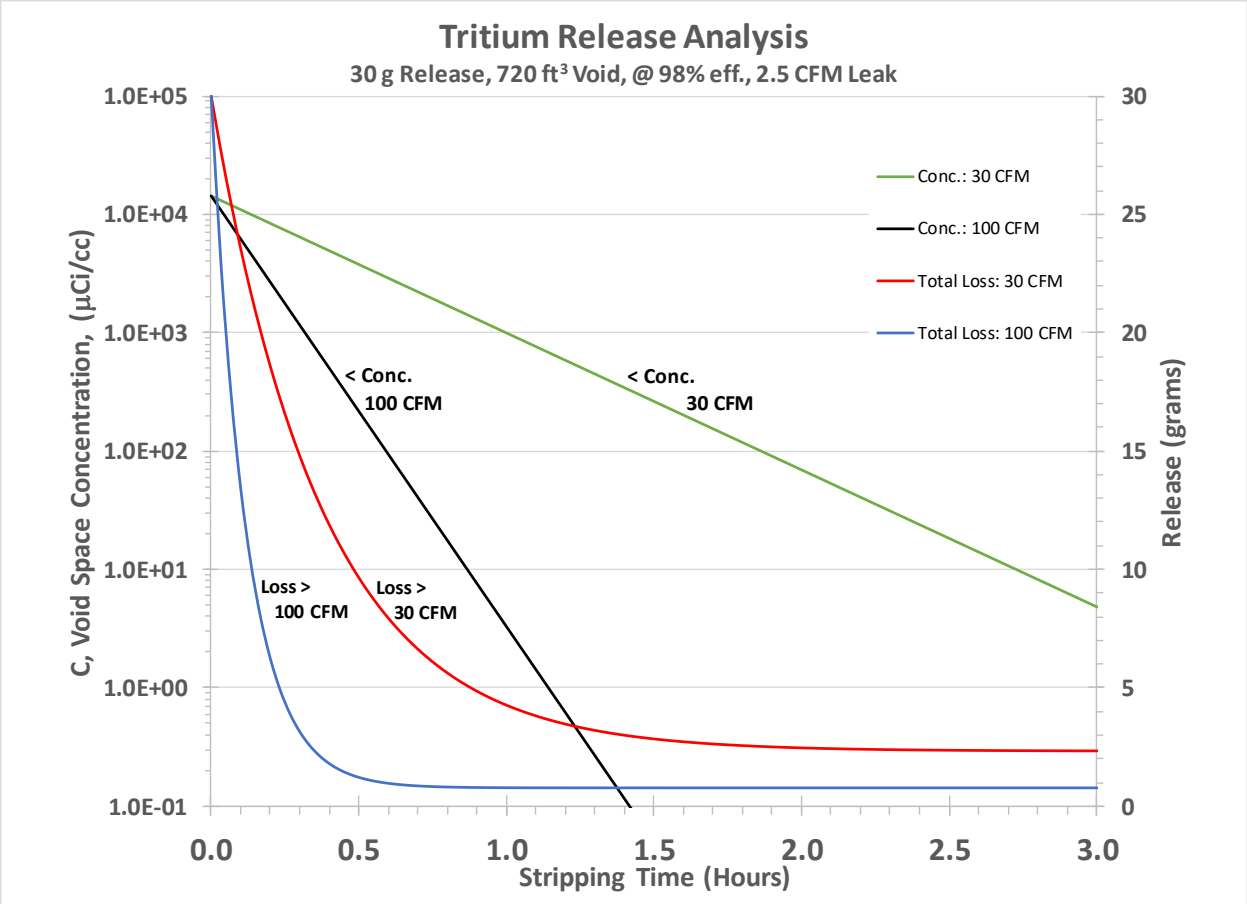

Figure 4-1 – Tritium Release Analysis of 30 g Tritium in a 720 ft^3 Volume

The 30 CFM stripper recovers 92.1% of the tritium after 3 hours (2.351 g recovered of 2.359 g recoverable) while the 100 CFM stripper recovers 97.5% of the tritium after 3 hours (releases 0.7463 g). For comparison, it takes a little over 20 minutes for the 100 CFM stripper to capture the same quantity of tritium as the 30 CFM stripper operating for 3 hours. Considering the 100 CFM stripper is over three times larger than the 30 CFM stripper system for a 5.4% increase in tritium recovery, the 30 CFM stripper will be considered the appropriately sized system to deploy – especially since the analysis assumed release of 100% of the maximum facility inventory. Baseline conditions for the remainder of the report will be for Q_0 of 30 g, F_L of 2.5 CFM, and F_S of 30 CFM at an ε of 98% efficiency. $R_{T,min}$ calculated from Equation 14 with these values equals to 2.351 g. Q_A will be rounded to 2.400 g unless a distinction is needed to illustrate tritium release values higher than those obtained from stripping and leaking at infinite time.

4.2 Stripper Flow Rate Analysis

The stripper flow rate of 30 CFM is roughly equivalent to using six Metal Bellows (MetBel) Model MB-602 pumps with both pump heads piped in parallel flow (designated MB-602-P) with each pump producing an output flow of 5 CFM (out a maximum of 6 CFM for the pump). Figure 4-2 shows the transient tritium stripper recovery using Equation 9 for Q_0 of 30 g, a 2.5 CFM leak rate, and a 98% stripper efficiency for different stripper flow rates, i.e. various numbers of MB-602-P pumps. Table 4-1 shows changes in minimum tritium releases, $R_{T,min}$, for different flow rates using Equation 14. It should be noted the reduction in tritium losses is not proportional to the incremental increase in the number of pumps added to the stripper system. Space and costs may eventually become factors which begin to outweigh the benefits of increased stripper size since larger flow rates will likely require proportionally larger stripper beds.

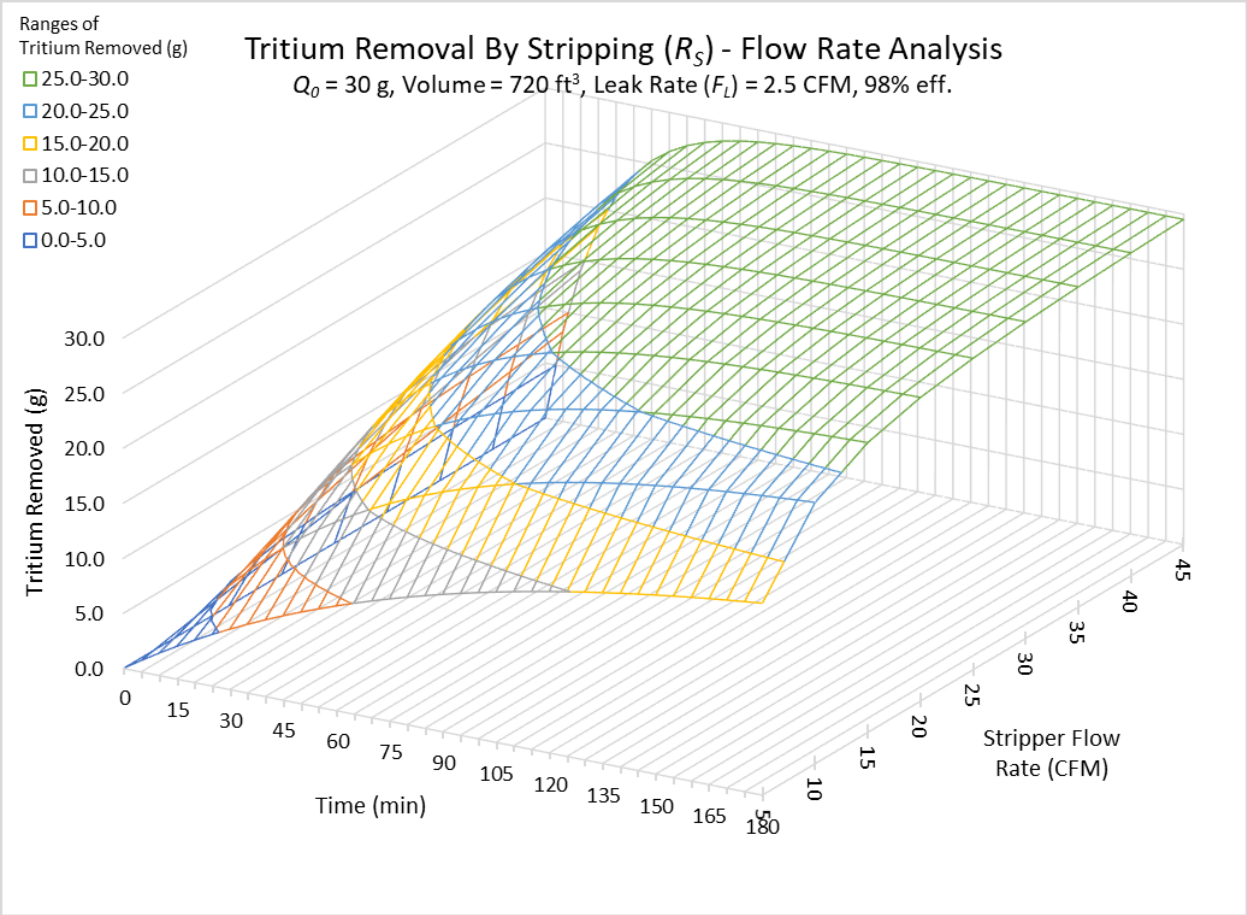

Figure 4-2 – Transient Tritium Recovery (R_S) for 30 g Release for Different Stripping Rates

Table 4-1 – Minimum Tritium Releases for Different F_S Rates[a]

Initial Tritium Release (g)	Stripper Rate						
	15 CFM	20 CFM	25 CFM	30 CFM	35 CFM	40 CFM	45 CFM
30	4.361 g	3.394 g	2.778 g	2.351 g	2.038 g	1.799 g	1.609 g
15	2.180 g	1.697 g	1.389 g	1.176 g	1.019 g	0.899 g	0.805 g
7.5	1.090 g	0.848 g	0.694 g	0.588 g	0.510 g	0.450 g	0.402 g

[a]Equation 14 values for 2.5 CFM leak rate and 98% stripper efficiency.

In some loss of power scenarios, back-up power can only be supplied to a limited number of pumps. Figure 4-3 shows Equation 16 maximum F_L values as a function of Q_0 for the baseline case of Q_A equals 2.4 g for F_S of 30 CFM and 5 CFM (one MB-602-P pump) both operating at 98% efficiency. The figure shows if the

initial tritium release can be reduced, the maximum leak rate can be larger and mitigate releases to the same Q_A value. The figure also illustrates that with a reduced stripper flow rate, the maximum allowable leak rate to achieve a fixed value of Q_A requires reduced leak rates. Reduced stripper flow during a loss of power may require an active response (e.g. closing of dampers or isolation valves) to reduce tritium leak rates from the system.

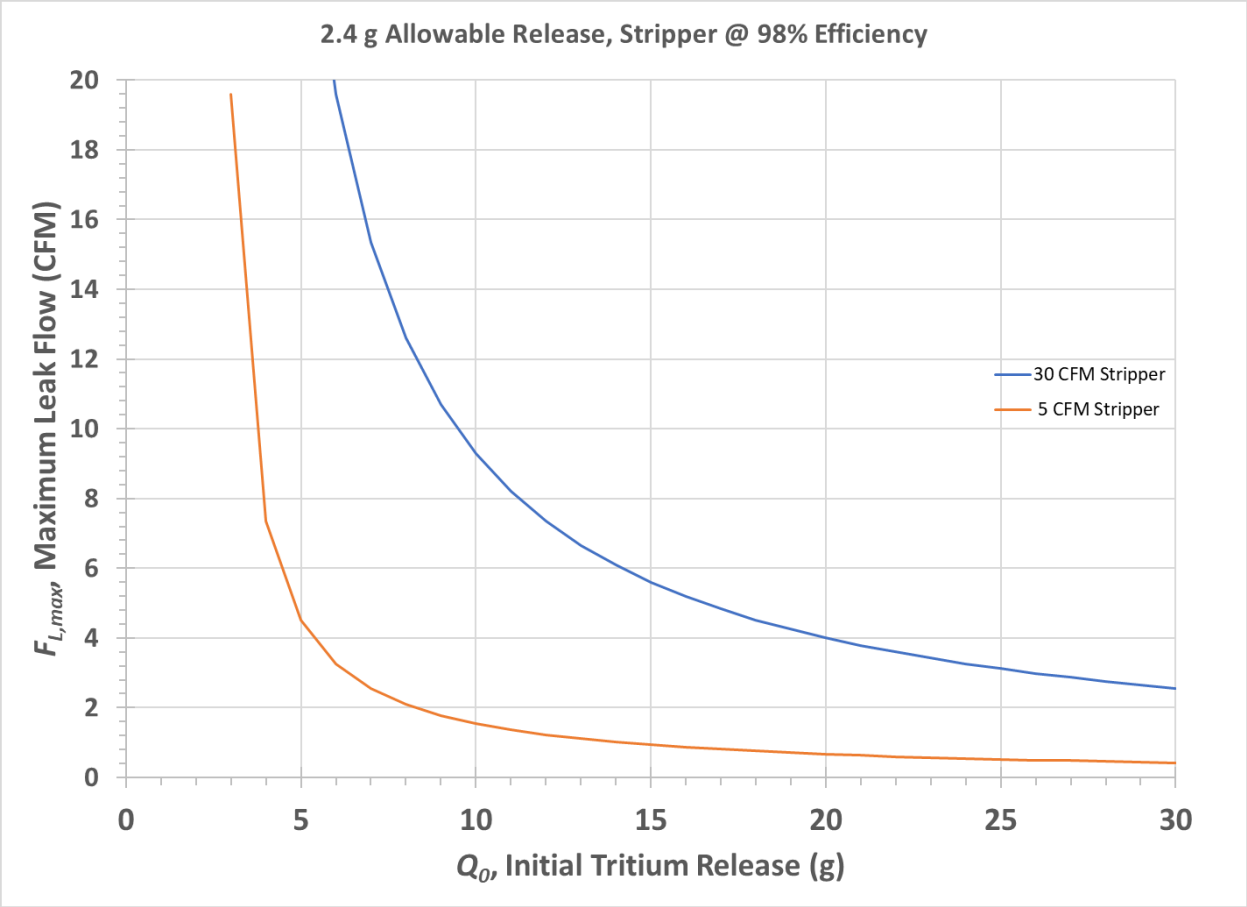

Figure 4-3 – Required Leak Flow Reduction for Lower Tritium Stripper Flows due to Loss of Power

For only one pump operating (F_S = 5 CFM) for Q_0 of 15 g and Q_A of 2.4 g, $F_{L,max}$ from Equation 16 is 0.933 CFM. This leak rate value is approximately 100 times greater than the total estimated air in-leakage rate, 9.46×10^{-2} CFM, to a similarly sized (770 ft^3), previously analyzed glovebox. The glovebox in-leakage rate was speculated to increase by two orders-of-magnitude from its nominal value after a DBA seismic event which could increase the in-leakage rate to a negative pressure glovebox through degraded electrical feedthrough connectors.

Figure 4-4 shows the Equation 19 minimum required stripper flow rate versus Q_0 for a 2.5 CFM leak rate, a stripper efficiency of 98%, and Q_A of 2.4 g. Results are also shown for Q_A of 1% of the maximum 30 g

inventory: 0.3 g. As seen in the figure, the minimum required stripper flow rate increases greatly as Q_A decreases, but it decreases as the amount of tritium initially released (Q_0) decreases.

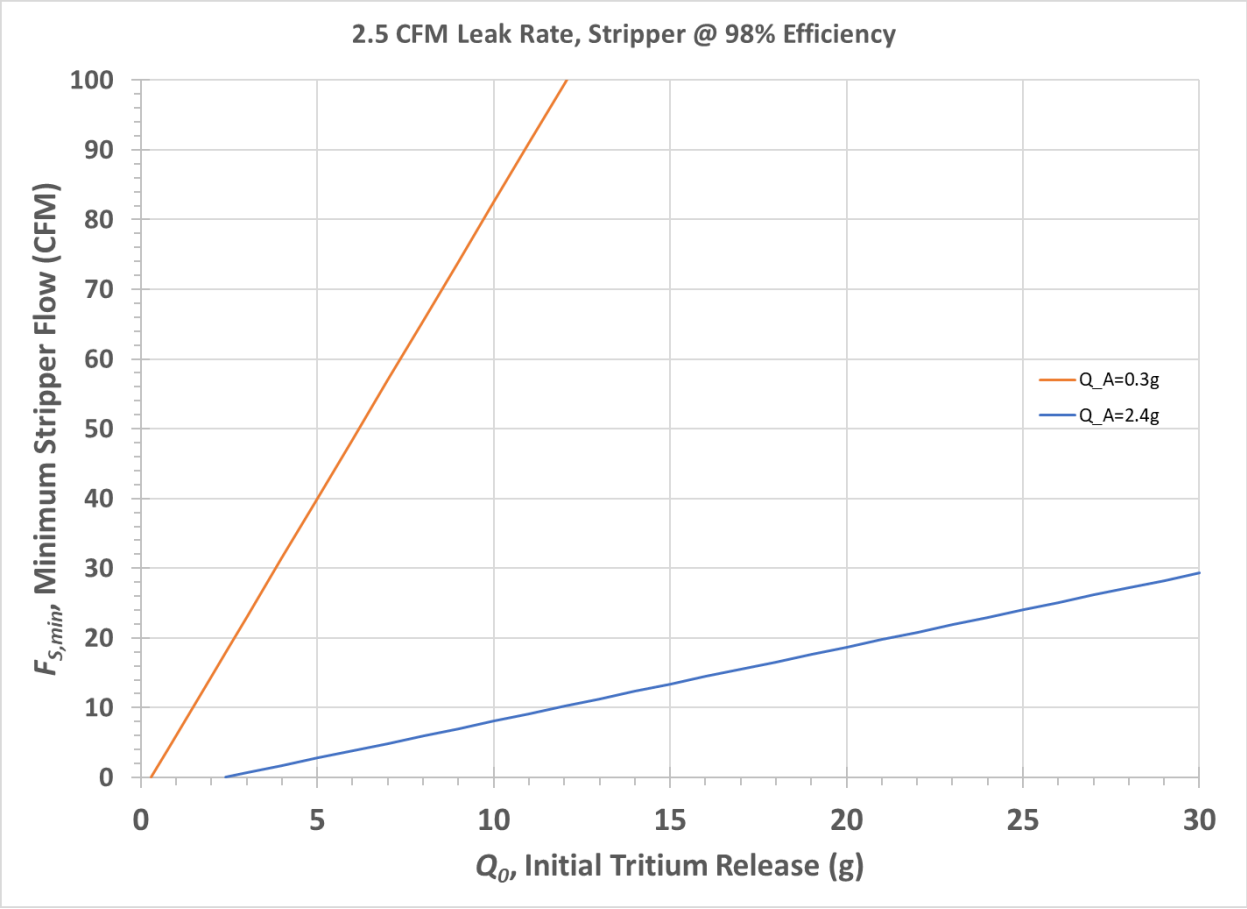

Figure 4-4 – Minimum Stripper Flow for 0.3 and 2.4 g Maximum Allowable Release

4.3 Leak Ratio/Rate Analysis

Equation 17 shows the relationship between the two key ratios for these analyses: the *LR* (F_L over F_S) and DF_{min} (Q_0 over Q_A). Figure 4-5 shows Q_A calculated from Equation 15 as a function of Q_0 for select *LR* values with the stripper efficiency set to 100% to simplify the discussion. The figure shows for a fixed Q_A value, the required *LR* varies with Q_0. For example, for an allowable release of Q_A equal to 1.0 g, an *LR* value of 0.20 requires Q_0 to equal 6.0 g. For a smaller *LR* value of 0.10, Q_0 increases to 11 g to maintain Q_A at 1.0 g. For another 50% reduction in *LR* value to 0.05, Q_0 can be as high as 21 g. The emphasis on mitigation to reduce Q_0 can compensate for *LR*s being larger than desired for specified Q_A values.

Table 4-2 illustrates the sensitivity of $R_{T,min}$ calculated using Equation 14 for various Q_0 values (7.5, 15, and 30 g tritium) and two leak rates: 100% and 50% of the baseline scenario. For the baseline case of Q_0 of 30 g, and F_S of 30 CFM operating at 98% efficiency, $R_{T,min}$ is 2.351 g at a 2.50 CFM leak rate and will reduce proportionally with reduced Q_0 values. However, a 50% reduction in leak rate flow from 2.50 CFM to 1.25 CFM does not reduce $R_{T,min}$ by 50%: 2.351 g to 1.224 g (for Q_0 of 30 g) which is approximately a 48% reduction in $R_{T,min}$ due to the non-linear relationship of Equation 14 between Q_0 and F_L.

Figure 4-5 – Allowable Release (Q_A) versus Initial Release (Q_0) for 100% Efficient Stripper

Table 4-2 – Minimum Tritium Releases for Initial Release and Leak-Rate Reductions[a]

Initial Tritium Release (g)	Leak Rate	
	1.25 CFM	2.50 CFM
30	1.224 g	2.351 g
15	0.612 g	1.176 g
7.5	0.306 g	0.588 g

[a]Values from Equation 14 for 30 CFM stripper operating at 98% efficiency.

5.0 Discussion

Several variables must be taken into consideration when designing, building, and operating a stripper system for a shielded cell or glovebox.

5.1 Stripper System Nominal Flow Effect on Tritium Releases

As described in the previous scenarios and calculations, if the leak rate (F_L) is known or specified, then the appropriately sized stripper system can be installed to ensure the requirements of Equation 19 are met or exceeded. Conversely, if the stripper size is known (F_S), then Equation 16 can be used to define design criteria for the leak rate of the enclosure. As shown in Figure 4-3, Figure 4-4, and Figure 4-5, mitigation of the amount of tritium which can be released (Q_0) in a DBA can reduce the size of the stripper system or relax the requirement of very low F_L values.

It is recognized that few installed tritium stripper systems exhibit the concentration versus time characteristics as shown here – especially after a reduction of initial concentration by 2 to 3 orders of magnitude.[3-5] Tritium concentration versus time results produce an observed plateau of tritium concentration in the cell atmosphere, long after ideal models would predict lower concentrations.

5.2 Tritium emissions impact due to materials

The materials of construction for walls of shielded cell tritium confinement systems is another important design consideration. Stainless steel has been shown to allow for ideal tritium removal after having residence times lasting up to one week in a dry (<600 ppm H_2O) atmosphere.[4] On the other hand, porous materials such as cement or concrete offer an opportunity for tritium to adsorb onto the surface, interact with waters in the material, or permeate through the material. This can create additional environmental/personnel safety concerns.

Studies have been performed demonstrating the permeation rate of tritium through cell construction material.[6,7] It was reported that using a porous material will result in the permeation of tritium into the outside environment in a relatively short amount of time, without any sort of stripper system in place.[6] It was also noted that when using a stripper system, tritium that had permeated into the walls initially will be re-emitted from the walls back into the cell due to the change in concentration gradient for tritium movement into the material.[8] This tritium desorption from the walls back into the cell will result in the observance of a plateau of detectable tritium in the cell atmosphere.

In an atmosphere containing moisture slightly below saturation, the permeation rate of tritium through a concrete wall may be hindered due to the narrowing of pores by adsorbed water on the concrete surface,[6] however, due to the pore sizes of the material and the overall adsorption levels, this hindrance may be minor, if not negligible.

The main point is if the walls of the cell continually desorb tritium, tritium stripping of releases to low-levels such as DAC-HT and DAC-HTO will likely not be possible. Adsorption and desorption of tritium into the cell walls will play a role in how low measured tritium concentration values can be obtained. The calculations used in the referenced reports may help determine at what point cell wall decontamination measures are required since continued stripper operation will have little impact of the measured concentrations in the cell. Wall liners, coatings, or epoxies should be considered to help mitigate continual tritium off-gassing from the walls.[8]

5.3 Recommended Detritiation Strategy

Use of a single stage, recirculating stripper system, as opposed to a multi-stage system, offers a reasonable compromise between tritium recovery and stripper system size and cost. Multi-stage systems may be beneficial for continuously stripped systems (e.g. operating glovebox operations) versus infrequently used, standby systems with a possibility of never being deployed. Multi-stage stripper systems offer little benefit over a single-stage system for extremely large tritium releases when tritium re-emittance or off-gassing from the walls continually elevate tritium concentrations unless stripping is done for an extended duration while the tritium is slowly released from surfaces so it can be captured by the stripper system. If long term stripping is not possible or desired, decontamination of the walls is then needed to reduce off-gassing of tritium to restore tritium concentrations closer to pre-release levels.

6.0 Conclusion

The detritiation model presented in this paper represents a high-level analysis of tritium recovery versus losses for "leaky" confinement enclosures after large tritium releases. Key parameters for doing the analyses are the system leak rate, stripper flow rate, initial tritium release, and allowable tritium release values. Worse-case scenario analysis assumed complete release of a 30 g tritium inventory in a Hazard Category III Nuclear Facility; although, the methodology applies for different releases. A comparison between use of a 100 CFM and 30 CFM stripper system revealed the benefits of a 100 CFM system could be matched by using a 30 CFM system with provisions of either reducing system leak rates, mitigating the magnitude of the initial quantity of tritium released, or both. The stripper system removes the majority of the tritium released and can be designed to meet environmental release limits. Residual contamination of the cell walls is another consideration to be addressed after a DBA since tritium stripping will not likely produce atmospheric tritium concentrations which will allow personnel to enter the enclosure (if needed) due to tritium interactions with the walls which can off-gas for extended periods of time.

7.0 References

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