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1400 Opus Place
Downers Grove, Illinois 60515

November 12, 1991

Dr. Thomas E Murley
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C 20555

Attn: Document Control Desk

Subject: Dresden Station Units 2 and 3
Quad Cities Station Units 1 and 2
Request for Exemption from 10CFR50
Appendix J Type B Testing Requirement for
Two-Ply Containment Penetration Bellows
NRC Docket Nos. 50-237/249 and 50-254/265

References: (a) T. J. Kovach to A. Bert Davis letter dated March 27, 1991

(b) R. Stols to T. E. Murley letter dated April 19, 1991

(c) R. Stols to T. E. Murley letter dated August 15, 1991

(d) Conference Call on October 22, 1991 between CECo (J. Schrage, et al), NRR (L. Olshan, et al) and Region III (M. Phillips)

Dear Dr. Murley:

During the Quad Cities Unit 1, Cycle 11 Refueling Outage, Commonwealth Edison Company (CECo) identified that two-ply flexible metallic containment penetration bellows at Dresden and Quad Cities Stations could not be properly tested to meet 10 CFR 50 Appendix J Type B test requirements. CECo notified the Commission of the investigation in reference (a). This document provided information pertaining to a 10 CFR 21 Notification for Type B testability of two-ply containment penetration bellows. Additional information was provided to the Commission in reference (b).

As part of the investigation of the two-ply bellows, CECo investigated several alternate methods to conduct acceptable testing of the bellows assemblies. To date, no acceptable testing method has been validated. CECo, however, has developed a procedure which will ensure that the bellows assemblies are properly examined during refuel outages. This procedure was originally transmitted in reference (c), and has been discussed several times with members of the NRC staff (including NRR and Region III). In the referenced teleconference, CECo presented additional data which validated the ability of the test procedure to detect leaks. During that teleconference, concurrence with our proposed test procedure was obtained from NRR and Region III.

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Based upon the inability to perform a Type B test, and the validation of the proposed testing procedure to detect leaks, CECo requests an exemption from Appendix J Type B testing requirements for two-ply containment penetration bellows in accordance with 10 CFR 50.12(a)(2)(iii). In lieu of an acceptable Type B test, CECo will perform the proposed test procedure described in Enclosure B. This procedure includes the performance of a Type A test during each refuel outage. This testing program will be continued for each of the applicable bellows assemblies until it is replaced with a testable bellows, or until a valid Type B testing method is developed. If the test procedure indicates leaks through both plies of a two-ply bellows assembly, CECo will replace that bellows assembly during the next refuel outage, or provide justification to the NRC for continued operation greater than one operating cycle.

An exemption from Appendix J Type B testing requirements is appropriate in this situation based upon the costs required to comply with the requirements. These costs would be significantly in excess of those contemplated when the regulation was adopted, and significantly in excess of those incurred by others in similar situations. A complete cost analysis is described in Enclosure B.

The proposed exemption request is subdivided as follows:

Enclosure A: Circumstances Surrounding the Exemption Request

Enclosure B: Basis for the Exemption Request

Enclosure C: Supporting Justification for the Exemption Request

To the best of my knowledge and belief, the statements contained above are true and correct. In some respect these statements are not based on my personal knowledge, but obtained information furnished by other Commonwealth Edison employees, contractor employees, and consultants. Such information has been reviewed in accordance with Company practice, and I believe it to be reliable.

If there are any comments or questions pertaining to this exemption request, please direct them to John L. Schrage at 708-515-7283.

Respectfully,

John L. Schrage
Nuclear Licensing Administrator

Attachment

cc: A. Bert Davis, Regional Administrator - RIII
L.N. Olshan, Project Manager - Quad Cities
T.E. Taylor, Senior Resident Inspector - Quad Cities

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ENCLOSURE A

CIRCUMSTANCES SURROUNDING THE EXEMPTION REQUEST

During the Quad Cities Unit 1, Cycle 11 Refueling Outage, Commonwealth Edison Company (CECo) performed a local leak rate test (LLRT) on the Drywell Ventilation Penetration X-25 bellows on November 19, 1990. The measured leakage rate was 4.3 scfh. After the LLRT was performed, a significant amount of maintenance and new construction work was performed in the area surrounding the bellows assembly. This included extensive maintenance on a valve located in-line with the bellows (valve 1-1601-23), and installation of a new penetration (X-109, Reactor Vessel Level Instrumentation Lines) directly above X-25. After the completion of this maintenance and construction, a new LLRT was performed on the X-25 bellows, with a measured leakage rate of 6 scfh. Approximately two days later, the primary containment Integrated Leak Rate Test (ILRT) was performed. While the containment was at pressure, application of a soap solution to the surface of the X-25 bellows indicated three cracks ranging in length from 0.187" to 1.7", and a large number of small pin-hole cracks. The ILRT was successfully completed with the leaking bellows in its as-found condition. Following the ILRT, an additional LLRT was performed on the bellows, and the results matched the previous LLRT leakage rate. A soap solution was applied to the bellows assembly during this LLRT and showed only a few small leaks.

Next, a "special" LLRT was performed in an effort to quantify actual leakage from the bellows. A steel plate was welded to the vent line inlet which is located inside the drywell. The bellows were pressurized through a threaded hole in the plate and a leak rate test was performed on the entire penetration. The soap solution indicated a large leak with many small leaks similar to that encountered during the ILRT. A leakage rate of 137 scfh was measured.

With the validity of the LLRT in question, the station implemented a method of determining the sensitivity of the LLRT procedure to detect and quantify leaks. A 0.25 inch hole was drilled through the two bellows from the outer diameter to the inner diameter in the convolute adjacent to the LLRT taps on the bellows. A LLRT was performed and resulted in a small increase in leakage (from 6 scfh to 7 scfh). A second hole was drilled and the LLRT was repeated. The measured leakage was 8 scfh.

These circumstances indicated that the current method used to perform a LLRT on two-ply containment penetration bellows could identify leakage, but could not quantify the extent of the leakage. CECo formally notified the Commission of these findings in reference (a).

The bellows assembly for penetration X-25 at Quad Cities Station are typical of two-ply bellows for other containment penetrations at both Quad Cities and Dresden Stations. These assemblies are original plant equipment, which were manufactured and installed in the late 1960's and early 1970's. These flexible metallic bellows are constructed with two plies of austentic type 304 stainless steel which are formed together into cylindrical corrugated bellows elements. This design configuration is typical of bellows penetrations which are utilized for all units at Dresden and Quad Cities Stations. The investigation conducted by CECO, which included discussions with the supplier and an independent analysis at Argonne National Laboratory, revealed that the forming process can bring the plies into contact, thereby limiting the flow of the local leak rate test medium (inert gas or air) between the inner and outer plies. The X-25 LLRT and ILRT test results indicate that leakage can be detected under these conditions, however, the leakage cannot be accurately quantified. In addition to an evaluation of the Type B testability of two-ply bellows assemblies, CECo has performed an investigation into the cracks found in the X-25 bellows assembly. Metallurgical examination of the bellows revealed that the crack mechanism was transgranular stress corrosion cracking (TGSCC). This mechanism is consistent with previous bellows assembly deterioration which has occurred at Dresden and Quad Cities Stations.

TGSCC is normally characterized by the slow development and propagation of cracks. The X-25 penetration deterioration is unique in that the bellows appeared to exhibit a large increase in leakage during one operating cycle, based upon the potential impact of 137 scfh on the ILRT results. This large amount of leakage would have had a noticeable impact upon ILRT results during previous outages (although it would not have led to the failure of the ILRT). This significant leakage increase may have occurred as a result of maintenance work associated with the replacement of a valve which is directly in-line with the bellows. During the replacement of the in-line valve (1-1601-23), which is located approximately 12 inches from the bellows assembly), excessive force was used to remove the valve. Resultant torsional and/or translational forces may have caused an accelerated growth of existing TGSCC cracks in the bellows. The metallurgical investigation also identified the presence of several corrosive species which contribute to TGSCC. These included chlorides, flourides, and sulfides. The original form of this material could not be determined and the method of substance deposit is therefore unknown.

A fracture mechanics evaluation for the X-25 bellows was performed to determine the margin to structural failure as a results of crack propogation due to mechanical fatigue and TGSCC. The fracture mechanics evaluation determined the following parameters:

a. The critical length of an axial through-wall crack which would result in unstable crack growth and thereby resulting in catastrophic failure of the bellows assembly,

b. the number of lateral motion cycles which are required to achieve the critical crack length utilizing conventional austenitic fatigue crack growth rate, and

c. the number of lateral motion cycles which are required to achieve the critical crack length with TGSCC crack growth and conventional austenitic fatigue crack growth rate.

The fracture mechanics evaluation determined the critical length of an axial through-wall crack to be 4.99 inches. The evaluation revealed the following:

a. For the 1.7" axial through-wall crack to reach critical crack length, 363 lateral motion cycles would have to occur. (A lateral motion cycle is defined as the lateral deflection of the bellows through a range of 0-1.785" which is the design condition associated with a loss-of-coolant accident.)

b. For the crack to grow to critical length under more realistic assumptions (i.e., lateral displacements through a range of 0-1.02"), 2,771 lateral motion cycles would have to occur in order to achieve critical crack length.

c. For the case of conventional austentic fatigue and TGSCC crack growth, 316 lateral motion cycles would be required to reach the critical crack growth.

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The fracture mechanics evaluation demonstrated that substantial structual margin exists to ensure that during the operating cycle, catastrophic failure of the containment penetration bellows assemblies should not occur. During a typical operating cycle, the number of lateral displacements which would occur due to normal thermal cycles was conservatively estimated at approximately four (4). The calculation demonstrates that approximately 363 lateral motion cycles (under the most conservative design condition) would be required for the existing crack to reach critical crack length.

The evaluation also included the impact of fatigue on the failure of the bellows. To date, there has been no evidence that the cause of the deterioration is associated with fatigue failure, thereby additional conservatisms are provided in the calculation. The evaluation also examined the potential failure due to TGSCC assuming the X-25 bellows conditions. The evaluation concluded that the X-25 bellows assembly would remain intact and capable of performing its design function through the operation cycle.

ENCLOSURE B

BASIS FOR THE EXEMPTION

Pursuant to 10 CFR 50.12(a), Commonwealth Edison Company is requesting an exemption for two-ply containment penetration bellows at Dresden and Quad Cities Stations from the requirements of 10 CFR 50 Appendix J, Section III.D.2(a) which states:

> "Type B tests, except tests for airlocks, shall be performed during reactor shutdown for refueling, or other convenient intervals, but in no case at intervals greater than 2 years."

This exemption request will apply to the two-ply containment penetration bellows listed in Table 1 for Dresden Station and Table 2 for Quad Cities Station.

An exemption from Appendix J requirements is appropriate under the current circumstancess based upon the criteria established in 10 CFR 50.12.a.2(iii). This regulation requires the presence of special circumstances in order for the Commission to consider granting an exemption. The regulation states that special circumstances are present whenever compliance would result in undue hardship or costs which are significantly in excess of those contemplated when the regulation was adopted, or significantly in excess of those incurred by others in similar situations.

As previously discussed, Commonwealth Edison has identified the inability to quantify leakage of two-ply containment penetration bellows at Dresden and Quad Cities Stations in accordance with 10 CFR 50 Appendix J Type B test requirements. In order to achieve full compliance with these requirements, both Dresden and Quad Cities Stations would be required to replace all two-ply containment penetration bellows with a testable bellows design.

The cost of replacement of two-ply bellows assemblies is projected to range between approximately $7.1 million and $9.5 million per unit for both Dresden and Quad Cities Stations. A detailed cost analysis is described in Table 3. The total cost of bellows replacement is projected to be approximately $33.35 million.

Based upon CECo's proposed testing program to insure that at least one ply of the two-ply bellows is intact, and to insure that primary containment leakage is less than 0.75 La, this short-term commitment of resources is not justified for the additional level of safety that it would provide.

Proposed Testing Program

In lieu of an Appendix J Type B test on the applicable two-ply containment penetration bellows assemblies at Dresden and Quad Cities Stations, CECo will implement the following testing program:

1. All two-ply bellows will be locally pressurized with air (between the plies), at a pressure of Pa. The leakage rate will be measured in accordance with station procedures. If leakage is less than 0.5 scfh, the bellows assembly will be considered to be intact, and no further testing on that bellows assembly is necessary.

2. If the leakage rate is greater than or equal to 0.5 scfh, then the bellows assembly will be locally pressurized at the test taps with helium (between the plies) at a pressure of Pa. The outer ply will then be tested for the presence of helium with a helium sniff detector. If no helium is detected, the integrity of the outer ply will be considered to be intact, and no further testing on that bellows assembly is necessary.

3. If helium leakage is detected through the outer ply, then the inner ply will be tested for the presence of helium. If no helium is detected, the integrity of the inner ply will be considered to be intact, and no further testing on that bellows assembly is necessary.

4. If helium is detected through both the inner and outer plies, then the protective covers will be removed, and the outer ply will be examined by penetrant and/or snoop testing. All observed flaw indications will be measured and mapped. Bellows assemblies which indicate leakage through both plies will not be considered to be intact.

5. All crack indications will be evaluated by the Nuclear Engineering Department (NED) and the current and projected leakage rate will be calculated. The NED review will include a structural assessment of the bellows with regards to critical flaw size.

6. Upon completion of the two-ply bellows testing program, a Type A ILRT test will be performed to verify primary containment integrity.

7. All two-ply bellows assemblies which demonstrate leakage through both plies will be replaced during the subsequent refuel outage, unless Commonwealth Edison Company provides justification for continued operation greater than one operating cycle.

This exemption and associated testing program is requested for each non-testable two-ply bellows assembly (original design). Upon replacement with a testable bellows assembly, that bellows will no longer be included in this exemption, and will be required to be tested in accordance with the normal Type B test program. Similarly, if a method is developed which insures a valid Type B test on one or more bellows assemblies, those bellows will also be excluded from the exemption, and will be required to be tested in accordance with the normal Type B test program.

TABLE 1

DRESDEN STATION

Containment Penetrations Subject To Exemption Request

Unit 2

X-105A	A Main Steam Line
X-105B	B Main Steam Line
X-105C	C Main Steam Line
X-105D	D Main Steam Line
X-106	Main Steam Line Drain
X-107A	A Feedwater Line
X-107B	B Feedwater Line
X-108A	Isolation Condenser Steam Line
X-109B	Isolation Condenser Return
X-111A	A Shutdown Cooling
X-111B	B Shutdown Cooling
X-113	Reactor Water Cleanup
X-116A	A LPCI Injection
X-116B	B LPCI Injection
X-123	RBCCW Supply
X-124	RBCCW Return
X-125	Drywell Vent
X-126	Drywell Return
X-115A	HPCI Steam Supply
X-130	Standby Liquid Control Inlet
X-144	CRD Return
X-147	Reactor Head Spray
X-149A	A Core Spray
X-149B	B Core Spray

Unit 3

X-105B	B Main Steam Line
X-105C	C Main Steam Line
X-105D	D Main Steam Line
X-106	Main Steam Line Drain
X-107A	A Feedwater Line
X-107B	B Feedwater Line
X-108A	Isolation Condenser Steam Line
X-109A	Isolation Condenser Return
X-111A	A Shutdown Cooling
X-111B	B Shutdown Cooling
X-113	Reactor Water Cleanup
X-116A	A LPCI Injection
X-116B	B LPCI Injection
X-123	RBCCW Supply
X-124	RBCCW Return
X-125	Drywell Vent
X-126	Drywell Return
X-128	HPCI Steam Supply
X-138	Standby Liquid Control Inlet
X-147	Reactor Head Spray
X-149A	A Core Spray
X-149B	B Core Spray

TABLE 2

QUAD CITIES STATION

Containment Penetrations Subject

To Exemption Request

Unit 1

X-7A	A Main Steam Line
X-7B	B Main Steam Line
X-7C	C Main Steam Line
X-7D	D Main Steam Line
X-8	Main Steam Line Drain
X-9A	A Feedwater Line
X-9B	B Feedwater Line
X-10	RCIC Steam Supply
X-11	HPCI Steam Supply
X-12	Shut Down Cooling Supply
X-13A	A LPCI Injection
X-13B	B LPCI Injection
X-14	Reactor Water Cleanup Suction
X-23	RBCCW Supply
X-24	RBCCW Return
X-25	Drywell Vent
X-26	Drywell Return
X-47	Standby Liquid Control

Unit 2

X-7A	A Main Steam Line
X-7B	B Main Steam Line
X-7C	C Main Steam Line
X-7D	D Main Steam Line
X-8	Main Steam Line Drain
X-9A	A Feedwater Line
X-9B	B Feedwater Line
X-10	RCIC Steam Supply
X-11	HPCI Steam Supply
X-12	Shut Down Cooling Supply
X-13A	A LPCI Injection
X-13B	B LPCI Injection
X-14	Reactor Water Cleanup Suction
X-16A	A Core Spray
X-23	RBCCW Supply
X-24	RBCCW Return
X-25	Drywell Vent
X-26	Drywell Return
X-47	Standby Liquid Control

TABLE 3

PROJECTED BELLOWS REPLACEMENT COSTS

A. Projected Cost per Penetration

1.	Engineering	$ 60,000
2.	Material and Fabrication	70,000
3.	Onsite Mechanical Construction Support	90,000
4.	Bellows Supplier Installation	177,000
	Total Cost (per penetration)	$ 397,000

B. Total Cost per Unit

UNIT	# OF PENETRATIONS	COST PER UNIT ($ 000's)
Dresden 2	24	$ 9,530
Dresden 3	22	9,130
Quad Cities 1	18	7,146
Quad Cities 2	19	7,543
Total Replacement Cost ($ 000's)		$ 33,349

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ENCLOSURE C

SUPPORTING JUSTIFICATION FOR THE EXEMPTION REQUEST

The proposed testing program for two-ply containment penetration bellows described in Enclosure B is based upon historical testing and replacement experience. Historical testing results have indicated that the percent change in leakage for two-ply bellows assemblies increases at a very slow rate. The replacement of bellows at Dresden and Quad Cities Stations have been based upon this slow growth in leakage rates, as well as the magnitude of the leakage rate.

The recent results of leak rate testing of penetration X-25 at Quad Cities Station indicated that the LLRT could not always quantify leakage from a bellows assembly. This conclusion was based upon the indicated versus actual LLRT results (see Enclosure A). Given the leakage rates of the Quad Cities X-25 bellows under different test scenarios (normal LLRT and "special" LLRT), and the historical testing and replacement program, CECo developed a threshold to indicate the presence of leaks from a two-ply bellows assembly. This leakage threshold was determined to be 0.5 scfh.

If this threshold is exceeded, CECo would treat a specific bellows assembly as requiring additional evaluation, and would initiate progressively restrictive testing requirements to insure that one ply of the assembly was intact. This would then be verified with a Type A test.

In order to insure that the air test and associated threshold of 0.5 scfh would detect leakage from a bellows assembly, CECo performed a one-time helium flow rate validation test on the two-ply bellows assemblies at Dresden Station. This validation consisted of two separate pressurizations and leak rate measurements, one with air at Pa, and one with helium at Pa. By pressurizing with helium, CECo would then be able to detect if an obstruction between the plies was preventing air from reaching a leak. The results of this validation test are described in Table 4.

The indicated helium leak rate for each bellows was corrected to account for the rotometer response to the different gases, and then corrected to the equivalent mass flow units for air. This value was then compared to the measured mass flow rate of air, and to the expected mass flow rate for both laminar and turbulent flow of helium. The calculations used to convert and compare the indicated helium flow rate to the flow rate of air are described in Table 5.

The corrected helium flow rate compares favorably with the expected flow rates of helium calculated for turbulent and laminar flow conditions. Therefore, the initial air leakage test described in the proposed test program is a valid means to test for the presence of leaks in two-ply bellows assemblies. This in turn validates the ability of the proposed testing program (which inludes a Type A test) to verify the integrity of a bellows assembly, and insure that primary containment leakage is less than 0.75 La.

TABLE 4

Drywell Penetrattion Bellows Testing; Air versus Helium
Test Date: October 19, 1991

#	Penetration	1 Air (scfh air)	2 Helium Corrected (scfh air)	3 Expected Helium Corrected Flow Rate Range (scfh)
1	X-105B	0.00	0.00 *	0.00 - 0.00
2	X-105C	0.00	0.00 *	0.00 - 0.00
3	X-105D	0.00	0.00 **	0.00 - 0.00
4	X-106	0.00	0.00	0.00 - 0.00
5	X-107B	0.00	< 0.04	0.00 - 0.00
6	X-113	0.00	< 0.04 *	0.00 - 0.00
7	X-116A	0.00	0.00 *	0.00 - 0.00
8	X-116B	0.00	0.00 *	0.00 - 0.00
9	X-123	0.00	0.00 *	0.00 - 0.00
10	X-124	0.00	0.00 *	0.00 - 0.00
11	X-126	0.00	0.00 *	0.00 - 0.00
12	X-128	0.00	0.00 *	0.00 - 0.00
13	X-149A	0.00	0.00 *	0.00 - 0.00
14	X-107A	1.00	0.12	0.126 - 0.394
15	X-108A	< 0.10	0.04 *	0.013 - 0.039
16	X-109A	< 0.10	0.07 *	0.013 - 0.039
17	X-111A	2.90	0.89	0.365 - 1.142
18	X-111B	0.19	0.09	0.024 - 0.075
19	X-125	0.80	0.44	0.101 - 0.315
20	X-138	0.83	0.41	0.105 - 0.327
21	X-147	0.18	0.07	0.023 - 0.071
22	X-149B	6.80	1.85	0.857 - 2.678

Column 1 = Mass flow rate of air in units of scfh-air.
Column 2 = Mass flow rate of helium in units of scfh-air; * indicates a one hour helium test and ** indicates a 30 hour helium test.

Column 4 = Expected mass flow rate of helium for laminar and turbulent conditions, given the mass flow rate of air from Column 1

" < " refers to an unmeasureable indication of leakage.

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TABLE 5

HELIUM FLOW RATE CORRECTION CALCULATIONS

A. Physical Constants

	Air	Helium
ℓ (lbs/ft^3)	0.0763	0.0105
μ (lb-sec/ft^2)	3.74E-7	4.1E-7
R (ft-lb/lb-°R)	53.35	386
γ	1.4	1.66

B. Rotometer Correction

If helium is passed through a rotometer calibrated for air, the indicated flow rate, Q_{ind}, must be corrected in order to find the actual helium flow rate, Q_{act}. This is accomplished with a correction factor.

$$CF_1 = \sqrt{\frac{\ell_{air}}{\ell_{he}}} = \sqrt{\frac{0.0763}{0.0105}} = 2.7$$

Therefore $Q_{act} = 2.7^* Q_{ind}$, where Q_{act} is the number of standard cubic feet of helium per unit time.

C. Helium to Air Corection

The flow rate of helium, Q_{act}, is expressed in units of scfh of helium. In order to compare this to a flow rate for air, it must be corrected to scfh of air. This involves a second correction factor.

$$CF_2 = \frac{\ell_{he}}{\ell_{air}} = \frac{0.0105}{0.0763} = 0.138$$

$$Q_{scfh\text{-}air} = Q_{act} * 0.138$$

Combining these two corrections result in the following equation.

$$Q_{scfh\text{-}air} = Q_{ind} * \frac{CF_1}{CF_2}$$

$$Q_{scfh\text{-}air} = Q_{ind} * 0.37$$

D. Expected Helium Flow Rates (scfh-air)

The expected flow through a bellows leak is bounded by laminar and turbulent flow conditions.

i. For laminar flow of a compressible fluid in a thin rectangular passage, the following equation describes the mass flow rate.

$$M = \frac{KAH^2}{\mu L} * \frac{1}{RT} * (P_c^2 - P_\alpha^2)$$

"Flow of a Compressible Fluid in a Thin Passage," S.K. Grinnel, Transactions of the ASME, May, 1956.

Where:
R = perfect gas constant, [(ft-lb)/(lb-°R)]
T = temperature, (°R)
L = length of leak, (ft)
μ = viscosity, (lb-sec/ft^2)
P = pressure, (lb/in^2)
M = mass flow rate, (lbs/sec)
A = area of hole (ft^2)
K = proportionally Constant
H = width of crack (ft)

Assuming a constant leak size:

$K_a = K_{he} = K$
$A_a = A_{he} = A$
$L_a = L_{he} = L$
$H_a = H_{he} = H$

$$M_{air} = \frac{KAH^2}{LT} * (P_c^2 - P_\alpha^2) * \frac{1}{R_a \cdot \mu_a}$$

$$M_{he} = \frac{KAH^2}{LT} * (P_c^2 - P_\alpha^2) * \frac{1}{R_{he}\mu_{he}}$$

$$\frac{M_{he}}{M_a} = \frac{R_a\mu_a}{R_{he}\mu_{he}}$$

solving for the mass flow of helium:

$$M_{he} = M_a * \frac{R_a\mu_a}{R_{he}\mu_{he}}$$

$$M_{he} = 0.126\ M_a$$

ii. For turbulent flow of a compressible fluid in a thin rectangular passage, the following equation describes the mass flow rate:

$$M = A_c \ P \sqrt{\frac{2g_c}{RT}} \sqrt{\frac{\gamma}{\gamma+1} \left(\frac{2}{\gamma+1}\right)^{\left(\frac{2}{\gamma-1}\right)}}$$

*J.P. Holman, Experimental Methods for Engineer's, 1971, p. 202.

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A_c = Leak Cross Sectional Area, (ft^2)
T = Air Temperature, (°R)
g_c = Gravitational Constant, (lb-ft)/(lb-sec^2)
R = Perfect Gas Constant, (ft-lb)/(R°-lb)
γ = Ratio of Specific Heats
P = Pressure, (lb/ft^2)

Assuming a constant leak size:

$$A_{c_{air}} = A_{c_{he}} = A_c$$
$$P_{air} = P_{he} = P$$
$$T_{air} = T_{he} = T$$

For air

$$M_{air} = A_c P \sqrt{\frac{2g_c}{R_a T_a}} \sqrt{\frac{\gamma_a}{\gamma_a+1}\left(\frac{2}{\gamma_a+1}\right)^{\left(\frac{2}{\gamma_a-1}\right)}}$$

For Helium

$$M_{he} = A_c P \sqrt{\frac{2g_c}{R_h T_h}} \sqrt{\frac{\gamma_h}{\gamma_h+1}\left(\frac{2}{\gamma_h+1}\right)^{\left(\frac{2}{\gamma_h-1}\right)}}$$

Dividing M_{he} by M_{air} and substituting for the values of γ_a and γ_h results in the following:

$$\frac{M_{he}}{M_{air}} = 0.394$$

$$M_{he} = 0.394 * M_{air}$$

Given the relationship between the mass flow rate of air and the mass flow rate of helium for laminar and turbulent flow conditions (as calculated above), the mass flow rate of helium (for a given mass flow rate of air) can be described by the following relationship.

$$M_{he} = (0.126 \text{ to } 0.394)\ M_a$$