ATR CONFINEMENT LEAKAGE DETERMINATION

P. Kuan and B. J. Buescher
Lockheed Martin Idaho Technologies Company
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625, Idaho Falls, ID 83415

I. INTRODUCTION

The air leakage rate from the Advanced Test Reactor (ATR) confinement is an important parameter in estimating hypothesized accidental releases of radiation to the environment. The leakage rate must be determined periodically to assure that the confinement has not degraded with time and such determination is one of the technical safety requirements of ATR operation. This paper reviews the methods of confinement leakage determination and presents an analysis of leakage determination under windy conditions, which can complicate the interpretation of the determined leakage rates. The paper also presents results of analyses of building air exchange under windy conditions. High wind can enhance air exchange and this could increase the release rates of radioisotopes following an accident.

II. ATR BUILDING LEAK TESTS AND THE LEAKAGE CURVE

The ATR reactor building is a structure about 200 ft by 200 ft and is divided into confinement and areas outside of confinement. The confinement is designed to act as the final barrier to delay the release of radioactive contamination from an accidental radioactive release. The confinement volume represents about 60% of the total building volume and special measures have been taken to limit the leakage from the confinement areas of the building. Penetrations through the confinement boundary have been minimized and are sealed by caulking or gasketing. Periodic building leak rate tests are run on the confinement part of the ATR building to assure that the confinement has not degraded. In this paper, unless specifically stated otherwise, the ATR building refers to the confinement part of the ATR building.

The first ATR building leak tests were performed in 1967, shortly after the completion of the ATR reactor. A fan was used to blow air into the building through a duct equipped with a flow control damper while all known leakage paths of the building were closed. Each control damper position corresponded to a constant air supply rate. As air was blown into the building, the pressure inside the building rose relative to the outside ambient atmospheric pressure. The air supply rate was equated to the building leak rate for that building inside volume-to-outside pressure differential when that pressure differential stabilized. Wind conditions during the tests were not explicitly stated in the referenced report, but was believed to be relatively calm.

Since 1981 the ATR building leak rate has been determined by a different, but simpler, pressure decay method. In this method, the building is pressurized above the outside atmosphere by supplying air to the building by a fan through a duct. When the pressure differential reaches

This work was supported by the U.S. Department of Energy, under DOE Contract No. DE-AC07-94ID13223.
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.
approximately 1" of water, the fan is turned off and a damper in the duct is closed to prevent air leakage through the duct. The pressure differential is measured as a function of time during the approximately one minute of time after damper closure when the building inside volume-to-outside pressure differential decays to zero as air leaks out of the building. The leak rate is calculated from the rate of pressure decay. Specifically, the leak rate is given by

\[ \text{Leak rate} = k \cdot (-\delta P / \tau P) \cdot V, \]  

(1)

where \( \delta P \) is the pressure change during time \( \tau \), \( P \) is the average absolute pressure of the building air during that time, and \( V \) is the free volume of the building. The proportionality constant, \( k \), can be either 1 (isothermal expansion assumption) or \( 1/\gamma = 1/1.40 \) (adiabatic expansion assumption), where \( \gamma \) is the ratio of specific heats of air. In an Engineering Design File analysis, it is shown that the adiabatic assumption should more closely reflect the air conditions during the pressure decay because of negligible heat transfer to the expanding air during that time. The free volume of the building is approximately \( 1.64 \times 10^6 \text{ ft}^3 \).

The measured leak rate versus differential pressure (Building \( \Delta P \)) is plotted in Figure 1. It is apparent from the plot that there is quite a bit of scatter in the data, particularly at the low end of "Building \( \Delta P \)." As remarked earlier, the data from the 1967 test probably were obtained during relatively calm conditions, but some of the data from the pressure decay tests may have been taken during conditions with light winds blowing from the south or southwest. Such winds tended to suppress leakage through the south and/or the west wall for the indicated "Building \( \Delta P \)'s", which were measured at the east wall. The effect of wind on test data presentation will be investigated more fully in the next two sections.

![Figure 1. ATR Building Leakage Curve.](image)

To obtain a curve that corresponds to the basic characteristics of the building regardless of ambient conditions, we assume that the test points near the upper bounds on the leak rate versus
building $\Delta P$ plot in Figure 1 represent the leakage of the building under no wind conditions. The fitted leak rate curve through these points is given by

$$L(\Delta P) \text{ (cfm)} = 3600 \left[ \sqrt{1 + \left( \frac{\Delta P}{0.12} \right)^{1.5}} \exp(-\Delta P/0.12) - 1 \right],$$

(2)

where $\Delta P$ is in inches of water. The mean deviation of the data from the values calculated from using Equation (2) is -1.0% (mean leak rates from data are less than calculated leak rates) and the root-mean-squared (RMS) deviation is 3.2%. Equation (2) will be used as the basic equation to predict leak rates from the building.

At high $\Delta P$ ($\Delta P >> 0.12''$ of water), Equation (2) can be approximated as

$$L(\Delta P) \text{ (cfm)} \approx 3600 \sqrt{\Delta P/0.12} = 10,400 \sqrt{\Delta P},$$

(3)

which has a pressure dependence that suggests turbulent flow through leakage paths or pressure drop from form losses for flows through leakage paths.

At low $\Delta P$ ($\Delta P << 0.12''$ of water), the exponential in Equation (2) can be approximated by 1 and a first order expansion of the square root yields

$$L(\Delta P) \text{ (cfm)} \approx 1800(\Delta P/0.12)^{1.5},$$

(4)

If the leakage flow is laminar, the leak rate would have been proportional to $\Delta P$. Instead, the leak rate drops off faster than linear with $\Delta P$. It is plausible that some leakage paths require a minimum $\Delta P$ to open up to leakage flow. As the pressure drops, more and more leakage paths are closed to flow, leading to a faster than a linear drop in leak rate. However, in the absence of a complete survey of building leakage paths, the above relationship between leakage rate and pressure differential should be considered as entirely empirical.

### III. WIND EFFECT ON LEAK RATE TESTS

**STATIC PRESSURE DISTRIBUTION AROUND THE ATR BUILDING UNDER WINDY CONDITIONS**

A simplified model of the ATR building is used to estimate the pressure distributions around the building with incident winds perpendicular or at 45° to one face of the building. The building is modeled as a square box, 200 feet by 200 feet, and 48 feet high, set on an impermeable base. The computational fluid dynamic code used to calculate the 3-D distribution of velocity and static pressure around the building is a commercially available code, Fluent/UNS, version 3.2 or 4.0. The downwind pressure is set at 12.5 psia and the downwind temperature is set at 80 °F, conditions representative of the atmosphere around the ATR building in summer time. To eliminate the hydrostatic component of the pressure with elevation, gravity is left out of the calculations.
The calculated average static pressure distributions around the building under windy conditions (wind speeds of 10 to 40 mph) are measured in reference to the static pressure in the atmosphere far away from the building. The results of the calculations for south winds show that the ratio of the elevated pressure at the south wall to the dynamic pressure of the wind \((1/2 \rho v^2\), where \(\rho\) is the density of air and \(v\) is the velocity of the wind) is fairly constant for all wind speeds in the calculations, and can be expressed as

\[
\text{South wall pressure elevation (in.-water)} = 1.218 \cdot \frac{1}{2} \rho v^2 = 1.218 \cdot 4.015 \times 10^{-4} v^2. \tag{5}
\]

The dynamic pressure at 12.5 psia and 80 °F for a wind speed of \(v\) (in mph) is used in the above formula.

Similarly, the elevated pressure at the west and south walls of the building relative to the pressure at the other faces of the building when a southwest wind is blowing can be expressed as

\[
\text{West/south wall pressure elevation (in.-water)} = 0.984 \cdot 4.015 \times 10^{-4} v^2. \tag{6}
\]

**WIND EFFECT ON LEAK RATE TESTS**

Under calm conditions the ATR building leakage characteristics is represented by Equation (2) given in Section II. The pressure differential, \(\Delta P\), is the difference between the building inside air pressure and the outside atmospheric pressure, both at the same elevation. The outside pressure tap is situated just outside the east wall of the building. When a wind is blowing from the south, the measured pressure differential, \(\Delta P\), will be higher than the pressure differential between the building inside air pressure and the atmospheric pressure just outside the south wall due to wind stagnation. The amount of \(\Delta P\) elevation as a function of wind speed is given by Equation (5). When a wind is blowing from the east, the atmospheric pressure just outside the east wall will be raised relative to the pressures outside the other faces and the roof of the building, so the measured pressure differential will be lower than the pressure differential at the other faces and the roof of the building. The amount of \(\Delta P\) depression as a function of wind speed is given by Equation (5). The leak rates determined in the presence of south or east winds will give the highest contrast from the leak rates determined under calm conditions. When the wind blows from any other direction, the leak rate as a function of the measured \(\Delta P\) should fall between the leak rates determined under the south wind and east wind conditions.

The locations of leakage paths around the ATR building have not been determined and probably can not be easily determined precisely. Absent such information, we assume that each face and the roof of the building leaks the same amount of air when the same pressure differential is applied across all faces and the roof of the building. We also assume that the leakage into the building is the same as the leakage out of the building when the pressure differential is reversed.
In the presence of a south wind, the average pressure differential at the south wall is depressed by an amount \( \Delta P_w \) given by Equation (5). The true pressure differential at the south wall, as opposed to the measured \( \Delta P \), is \( (\Delta P - \Delta P_w) \). The average pressure differential at other faces and the roof of the building is approximately the same as the measured pressure differential. The leakage from the south wall is

\[
L_{s,s} = (1/5) L(\Delta P - \Delta P_w), \quad \text{for } \Delta P \geq \Delta P_w \quad \text{and}
\]

\[
= -(1/5) L(\Delta P_w - \Delta P), \quad \text{for } \Delta P < \Delta P_w,
\]

where \( L(\bullet) \) is the function given by Equation (2). The leakage from the other faces and the roof of the building is

\[
L_{o,s} = (4/5) L(\Delta P).
\]

The total leakage from the building when there is a south wind blowing is

\[
L_{t,s} = L_{s,s} + L_{o,s},
\]

which is the quantity that is measured by the direct flow or pressure decay method.

In the presence of an east wind, the average pressure differential at faces other than the east face and the roof of the building is elevated by an amount \( \Delta P_w \) and is given by \( \Delta P + \Delta P_w \). The average pressure differential at the east wall of the building is approximately the same as the measured \( \Delta P \). The leakage from the east wall is

\[
L_{e,e} = (1/5) L(\Delta P).
\]

The leakage from the other faces of the building is

\[
L_{o,e} = (4/5) L(\Delta P + \Delta P_w).
\]

The total leakage from the building when there is an east wind blowing is

\[
L_{t,e} = L_{e,e} + L_{o,e},
\]

which is the quantity that is measured by the direct flow or pressure decay method.

The calculated leakage curve for the ATR building that would be obtained during tests in the presence of a south wind (\( L_{t,s} \), Equation (9)) is shown in Figure 2. Because of decreased leakage or even in-leakage from the south wall, the measured leak rate can be substantially below the leak rate under calm conditions for \( \Delta P \)'s less than a few tenths of an inch of water. For a south wind of 15 mph, no leakage or in-leakage would be detected at \( \Delta P \)'s below approximately 0.03 inches of water.
The calculated leakage curve for the ATR building that would be obtained during tests in the presence of an east wind (i.e., Equation (12)) is shown in Figure 3. Because the measured ΔP's are lower than the true ΔP's elsewhere around the building other than at the east wall, the measured leak rates would be higher than the leak rates under calm conditions, in contrast to the test results that would be obtained in the presence of a south wind. Figure 3 also shows a curve that is 125% above the curve for "No wind" conditions for all ΔP's. This curve would represent
the case when the building leakage areas have increased by 25% and the leak rates are determined under no wind conditions. If an east wind is blowing at 15 mph, the leakage test would give leak rates above the "125%" curve for ΔP's below 0.24 inches of water (critical ΔP); at 10 mph, the critical ΔP would be 0.14 inches of water. If there is a south (or southwest) wind blowing during a test, as shown in Figure 2, the effect of the wind is to depress the leak rate. To reliably detect building deterioration in leakage, it is therefore best to conduct the leak tests under no wind or light wind conditions. If a test has to be conducted under windy conditions, the test points should be limited to high ΔP's.

IV. WIND-INDUCED AIR EXCHANGE

We perform wind-induced air exchange calculations due to wind from the south and southwest directions. If we assume symmetry in leakage characteristics of the four walls of the building, the results can be applied to winds directly impinging on, and at 45° to, any face of the building.

The basic assumption of the air exchange calculations is the leakage curve obtained in Section II, Equation (2), for no wind conditions. The equation applies to the leakage of the entire building when the building volume is pressurized to ΔP above the surrounding atmosphere. When there is a wind blowing and the building is not pressurized artificially, at one or two faces of the building the outside pressure will be higher than the building inside pressure due to the impact of wind on the building. Air will leak in through these faces and the pressure inside the building will be elevated relative to the pressure outside the other faces of the building where air will leak out. Under a steady wind, air in-leakage equals air out-leakage.

Relative leakage through the faces of the building is not known. As a nominal case, we assume that each face of the building (four walls and the roof) leaks the same amount of air when the same pressure differential is applied to the faces. For the south wind case, air enters the building through the south wall and leaks out of the building through the remaining faces; for the southwest wind case, air enters the building through the west and south walls and leaks out of the building through the remaining faces. Both in- and out-leak rates are assumed to follow the same functional form of the leakage curve as given in Section II, Equation (1), but the constant in front of the equation is modified to reflect the relative leakage areas of the faces of the building. We denote $\mathcal{R}$ the ratio of the total in- and out-leakage areas to the total in-leakage area. The $\mathcal{R}$ for the nominal south wind case is 5 and the $\mathcal{R}$ for the nominal southwest wind case is 5/2. These are the cases when leakage from the building is divided equally among all faces and the roof of the building when the same pressure differential is applied across them. The $\mathcal{R}$'s are varied in both wind cases to show the sensitivity of the air exchange rate to this parameter.

For the south wind case, the wind pressure, $\Delta P_w$, on the south wall of the building is given by Equation (5) in Section III. We write ΔP as the building inside air pressure relative to the atmospheric pressure at faces of the building other than at the south wall.

By equating the in-leakage to the out-leakage, we obtain an equation for ΔP:

$$\frac{1}{\mathcal{R}} L(\Delta P_w - \Delta P) = \left[ (\mathcal{R} - 1)/\mathcal{R} \right] L(\Delta P),$$

(13)
where the function, $L(\bullet)$ is given by Equation (2) in Section II. For the nominal south wind case, $\mathcal{R} = 5$, and we have

$$\frac{1}{5} L(\Delta P_w - \Delta P) = \frac{4}{5} L(\Delta P).$$  \hfill (14)

The air exchange rate is given by either side of the above equation.

For the southwest wind case, we replace $\Delta P_w$ by Equation (6). Equation (13) is again used for the determination of the building inside air pressure, but now $\mathcal{R} = 5/2$, and we have

$$\frac{2}{5} L(\Delta P_w - \Delta P) = \frac{3}{5} L(\Delta P).$$  \hfill (15)

The air exchange rate is given by either side of the above equation.

Equations (14) and (15) are solved for $\Delta P$ by using Newton's method of iteration. The results are plotted in Figure 4 (south wind case) and Figure 5 (southwest wind case).

![Air Exchange Rate of the ATR Building in South Wind](image)

Figure 4. Air Exchange Rate of the ATR Building in South Wind ($\mathcal{R}=$ total to in-leakage surface area ratio).

The air exchange rates are generally less than 100\% per day of building free volume for wind speeds less than approximately 30 mph. From symmetry considerations, the maximum air exchange rates occur when the in-leakage surface area equals the out-leakage surface area ($\mathcal{R} = 2$). This case corresponds to a building inside pressure that is halfway between the upwind and downwind pressures just outside the building walls.
V. SUMMARY

From test data, both from the direct flow method used in 1967 and the pressure decay method used at present, we deduced in Section II a leakage curve for the ATR building under calm atmospheric conditions. This leakage curve is represented analytically by Equation (2) in Section II. The leakage flow is a function of the pressure differential ($\Delta P$) between the pressure of the building air and the atmosphere just outside the faces and the roof of the building. At high $\Delta P$'s, the leak rate is proportional to the square root of $\Delta P$, suggesting turbulent flow through cracks and other leakage paths of the building. At low $\Delta P$'s, laminar flow through cracks and other leakage paths of the building would give a linear relationship between the leak rate and the $\Delta P$. However, the actual leak rate falls off faster than linear with $\Delta P$. The cause of this behavior has not been determined.

In Section III, pressure distributions around the faces of the ATR building, together with the leakage curve obtained in Section II, were used to study the effect of wind on test data. The results show that, to accurately assess building leakage conditions, leakage tests are best performed under no wind, or light wind conditions. If tests are conducted under windy conditions, only leak rates determined for high building $\Delta P$'s give reliable indication of true building leakage condition. For example, for an east wind at 15 mph, the leak rates are not significantly affected by the wind for $\Delta P$'s above approximately 0.3 inches of water.

In Section IV, wind-induced leakage from the building was calculated for wind directions from the south and the southwest, the two prevailing wind directions at the ATR building. Air leaks into the building through the faces of the building facing the wind and leaks out of the building...
through the other faces. Balancing the in-leakage with the out-leakage gives the building inside overpressure. The results show that wind-induced leakage, or air exchange rate, is not likely to exceed 100% per day of the building inside free volume for wind speeds below approximately 30 mph.

The authors would like to thank Bob Kochan and Chang Oh for the Fluent calculations of the pressure distributions around the ATR building under windy conditions described in Section III, and John Dwight for very helpful comments concerning the ATR building and the leak tests.

VI. REFERENCES
