LOW FLOW CONTAINMENT AND VENTILATION DESIGN FOR NUCLEAR INSTALLATIONS

Dr. Ray Doig B.Eng., Ph.D., C.Eng., FCIBSE.

Principal Ventilation Engineer
BNFL Engineering Ltd., The Victoria
Harbour City, Salford Quays, M5 2SP, UK

Abstract

In the 1980's British Nuclear Fuels plc (BNFL) embarked on a major investment programme at its Sellafield site in Cumbria, UK. This involved constructing a large number of new plants, one of which is the Thermal Oxide Reprocessing Plant (THORP) plant. The guidance in existence at that time for nuclear ventilation designers was based on air change rate recommendations. If followed the ventilation systems would have been unacceptable in terms of size, operability, economics, dose to the operators and discharges to the atmosphere. BNFL was faced with developing new philosophies for the design of ventilation systems that are able to provide the performance required of them and at the same time be acceptable in safety and economic terms. This paper identifies the thinking behind the new philosophy that BNFL developed and now uses to design low flow ventilation systems that support the physical containment of a nuclear reprocessing/waste handling plant. The application of the philosophy to the Plutonium Finishing Line of the THORP plant is examined and feedback from the operating plant is used to establish its validity and demonstrate that safety performance has not been compromised.

Introduction

The primary task of any nuclear plant, irrespective of its other functions, has to be the prevention of loss of radioactive material to the environment. This is known as Containment or Confinement. The objectives of a combined containment and ventilation system are given in Figure 1. Note that containment and ventilation systems have to consider potential fault conditions and must be able to operate safely under those conditions. The ideal containment would be a completely sealed box, such as a fully welded metal can, and certain facilities do hold material in this manner. For reprocessing plants or waste handling plants, however, there is a need to access the material and the containment provided has penetrations to allow for this access, feeds in, wastes out and export of the final product. These penetrations are considered to be the weak points of the containment and as such require to be reinforced, so a further barrier is provided around the penetration. The second barrier also requires penetrations and a further barrier is provided. This approach produces a series of barriers each enclosing a contamination potential zone. The inner most zone having the greatest potential for contamination and the potential is progressively reduced until the outside environment is reached.

1. The containment of sources of radiation to protect the public, the plant operators and the environment under normal and incident conditions.
2. To control the atmosphere within process vessels.
3. To provide comfortable working conditions.
4. To minimise effluent arisings from ventilation and offgas cleaning.
5. To comply with statutory regulations and company policy.

Figure 1 : Aims of a combined Containment and Ventilation System.

Zone Barriers

Each of these barriers is not a complete seal and has a leak potential which is dependent upon the type of construction. This in turn can depend upon other functions that the barrier is also required to provide, e.g. biological shielding, seismic integrity, ease of construction and cost. Reinforced concrete is used extensively in the nuclear industry, but this alone cannot be expected to provide a high level of containment over a twenty year period, a common life expectancy of nuclear buildings. The BNFL design approach to cells, caves and canyons has been previously published. [1] The physical containment has to be reinforced with a ventilation system that provides a depression gradient across the successive barriers. The building shown in Figure 2 does not look much like the buildings we construct and operate. This is an idealised containment and shows the depression gradient provided by the ventilation system.

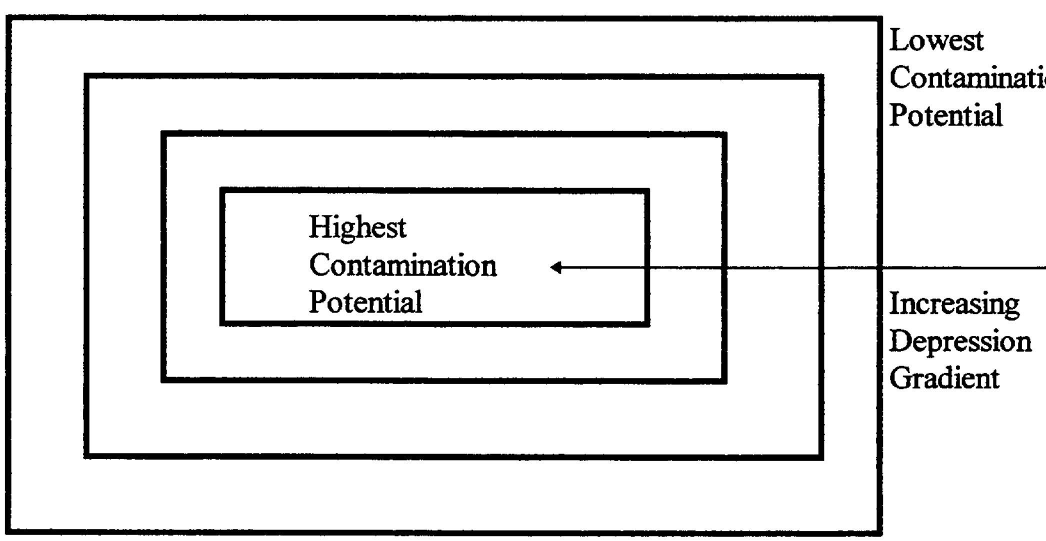

Figure 2 : Idealised Containment showing the depression gradient.

The ventilation system creates the depression gradient and thus air flows from the areas of low potential for contamination to areas of higher potential. By creating a difference in the static head either side of the barrier the ventilation system encourages air to flow in the desired direction. This flow of air increases the efficiency of the barrier and minimises the potential for spread of contamination. The ventilation system thus reinforces the physical containment. The combined containment and ventilation system can then control the potential for the spread of radioactive material through the building and hence to the environment.

Ventilation System Sizing

The above approach establishes the principles for the design of the containment system and the relationship with the ventilation system. It does not, however, provide a basis for the actual design or sizing of the ventilation system. It does not answer the question, 'How much air is required to pass through a particular zone?'

In the early 1980's BNFL was embarking on a programme of new facilities at its Sellafield site in Cumbria, UK. The THORP plant was a major part of that programme. The ventilation design guidance that existed in the UK at that time was AECP 1054, which gave recommended air change rates for nuclear facilities.(2) The problem facing BNFL was that the recommended volumes given in AECP 1054, Figure 3 equated to huge systems that would be extremely expensive to run and require considerable volumes of expensive building space for plantrooms and service distribution, etc. The cost of the ventilation system for a nuclear reprocessing building is of the order of 5% of the overall building. The cost of the space that the ventilation system requires for plant, equipment and distribution of ducting, etc. is an even greater proportion of the building costs.

BNFL undertook to review the basis of ventilation design and to establish if the practice of using air change rates could be improved upon, with the possible outcome of smaller ventilation systems. Ten years later as a result of the work undertaken on these BNFL projects AECP 1054 was re-issued and the recommended rates for ventilation were significantly reduced.(3) The new recommendations are given as Figure 3. (It should be noted that within BNFL, air change rates are not used as a basis of ventilation design, see later in the paper, but are used for comparison of one system to another.) BNFL developed a basis for ventilation design that moved less air, produced simpler, more economic systems and the changes have been shown to have had no detrimental effect on the safety of plants. How was this done and what is the basis of the BNFL containment and ventilation system design?

COMPARTMENT	1979 AIR CHANGE RATE	1989 AIR CHANGE RATE
Change rooms	4-5	4-5
Normally clean air corridors	5	1-2
Normally non-active rooms	5	1-2
Controlled areas of low potential hazard	5	2
Controlled areas of high potential hazard	10	5-10
Maintenance areas to primary containments of low risk process plants	5-10	1-5
Maintenance areas to primary containments of high risk process plants	30	10
Primary containments (glovebox, cell or cave)	2-30 depends entirely on process and hazards	30 depends entirely on process and hazards

Figure 3 : The recommended air change rates given in AECP 1054[2,3]. Columns 2 is taken from the 1979 issue and column 3 is taken from the 1989 issue.

Ventilation Design Basis

Traditional non-nuclear ventilation considers the occupants within the space being treated. An important function of the ventilation system is the supply of adequate oxygen to the occupants, as is the dilution of odours or contaminants to a socially, hygienically or environmentally acceptable level. The basic relationship between the ventilation rate and the room condition in terms of contaminant is given as;

$$X = Y / Z \qquad (1)$$

Where; X is the concentration of some contaminant (units/m^3).
Y is the arising rate of the contaminant (units/hour).
and Z is the ventilation rate (m^3/hour).

The contaminant may be heat, CO_2 or some arising of dust, etc. Using this approach the concentration of the contaminant can be reduced by increasing the ventilation rate within the space. Traditional non-nuclear ventilation is based on the historical experience of previous designs and experimental data which is collated and published by such bodies as ASHRAE in the USA and the CIBSE in the UK. These bodies publish literature that gives recommendations of ventilation rates for given circumstances.[4,5] For normal ventilation design this is perfectly adequate. However, is this approach valid for the nuclear industry and in particular for BNFL, is it valid for reprocessing and/or waste handling plants? The answer is no! The plants that BNFL build do **not** have a steady arising rate of contaminants! They are built to high standards of containment and a continuous loss of material would not be acceptable.

The situation within nuclear plants is more typified by a discrete release followed by a period of cleanup and airborne concentration reduction. Typically, there may be a release caused by an operation, for example maintenance, when usually contained equipment has to be dismantled to gain access for adjustment or repair. Following the maintenance, the area is cleaned and brought back to the original situation. If a ventilation rate were to be derived to reduce the airborne contamination associated with a discrete release it should be from the exponential decay curve;

$$C_t = C_0 e^{-at} \qquad (2)$$

Where; C_0 = Original Concentration (at time zero)

C_t = Concentration after time t hours

a = air change rate per hour

t = time in hours

On face value, it would appear that the concentration of a contaminant may be halved by doubling the ventilation rate of the room and so it can. The use of equation (2) is an improvement over the use of equation (1). However, the nuclear situation requires to be examined a little closer to establish if equation (2) is an adequate basis for the design of the ventilation rate for a space. Equation (2) makes the basic assumption that the contaminant is equally distributed around the space being ventilated and that there is sufficient of the contaminant for this to be the case.

BNFL has a design tool to classifying all the spaces within a facility in terms of radiation and contamination potential.[6] Figure 4 is an extract from this guide and presents the allowable levels of airborne contaminants in the various types of room within a BNFL plant. It also gives guidance as to the entry/exit control necessary.

Classification	Typical Type of Control	Mean Airborne Contamination (fraction of DAC)	Examples
C1	None	<0.01	All non-active areas
C2	Change outer clothing and shoes. Wash and monitor on exit	0.01 to 0.03	Operating areas
C3	Sub change provision. Boot change or overshoes. Outer clothing change where necessary. Respiratory (particularly in alpha areas). Frisking probe on exit.	0.1 to 1.0	Flask handling areas Alpha cubicles etc. Sampling suites 'Contact' areas where breaking of containment is possible
C4	Full sub change (where permanent requirement). PVC suits/boots/respirators. Full personnel checks on exit	1 to 10	Major in-situ maintenance areas. Temporary tented areas or spillage areas.
C5	requirement for routine access unlikely. Where access is catered for, space should be available to permit adequate contamination control arrangement.	Greater than C4	Total enclosures only.

Figure 4 : Relationship between room type and allowable airborne contamination as fractions of DAC. (extract from NF82/003).[6]

The fourth column of Figure 4 is headed Mean Airborne Concentration and gives allowable contaminant concentrations in fractions of Derived Air Concentrations (DAC). A typical DAC for a plutonium plant would be between 3 and 5 dpm. (disintegrations per minute, i.e. Bequerels/60). [7]

Using THORP as an example;

Specific Activity of Pu	=	1.8×10^{10} Bq/g (THORP Reference Fuel)
Specific Gravity (PuO_2)	=	11.46 g/cm^3
Derived Air Concentration	=	25×10^{-8} µg/m^3

This equates to a single particle 0.6 μm diameter/m^3. In terms of levels of dust most western industrialised cities have an atmospheric dust level between 30 and 80 μg/m^3. That is 10^8 times more concentrated that the amount of plutonium dust that gives 1 DAC. (Note that Figure 4 shows that BNFL operate C2 areas, where personnel do not wear respiratory protection to 1% of this level.) Thus the levels of material allowable in the breathing zone are so low initially that the applicability of the concentration decay curve is highly suspect. There can not be bulk volume of material initially and the levels of airborne material that are required to be achieved are so low that unreasonably long times would be required to reach the target level. In truth the amount of material that is airborne is not enough to allow a sensible application of the concentration decay curve, based on the requirement for the material to be equally distributed for the equation to be valid. BNFL concluded that the ventilation rate of a space has little effect on the control of the airborne contamination within that space, as the level of material airborne is not enough to make the bulk flow of air dominant. The only way of capturing this level of contaminant would be to adopt cleanroom technology and this was not though to be an acceptable approach for the nuclear industry.

BNFL Design Basis

At this stage the use of air change rates as a basis of the ventilation design for BNFL's new plants had been discounted, but no other basis had been established. BNFL had shown that ventilation rate has little effect upon the radiological contamination within a space and that a low flow would be just as effective as a high flow. Adopting a low flow option would mean that material would be settling out of the air onto the surfaces of the space. In the new plants BNFL has a policy of 'housekeeping' that includes regular swabbing of surfaces and cleanup campaigns for the purpose of cleaning away the material that settles. The material that does not settle will remain in the space until it is eventually captured by the extract system. The low flow increases the propensity for material to settle rather than remain airborne. Up to this point there is a potential for the airborne material to leave the space and escape to another area. The prevention of this spread of contamination is where the paper began and this is the true function of the ventilation system - support of the physical containment! The minimum amount of air required to pass through a space is that which must be drawn through penetrations in the boundary around the space to minimise the spread of contamination from that space. For most active area situations this means that spaces require extract ventilation only and that there is no direct supply to active area rooms, only cascaded air flowing into the space through engineered and adventitious routes.

Operational Plant Feedback

If the plutonium areas of THORP are examined, a typical glovebox cell would look like Figure 5. The building supply system provides air to the personnel corridor where workers do not wear respiratory protection. The air cascades from the corridor through an access facility into the glovebox cell. Personnel entering the cell wear respiratory protection to comply with the 'minimal inhalation dose' policy. There are two sources of extract on the cell. The first would be the glovebox extract and the rate of extract is so low as it can be ignored. The extract directly from the cell itself is sized to give a minimum velocity across the access facility.

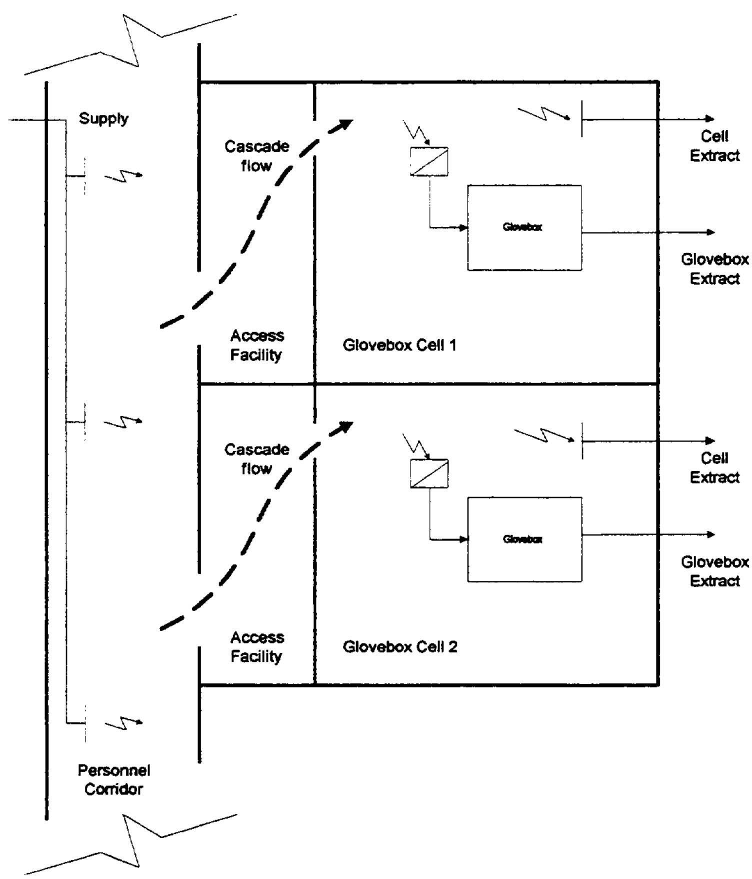

Figure 5 : Typical layout of personnel corridor and glovebox cells in the Plutonium Finishing Area of THORP. The supply air is delivered to the corridor (a C2 area) and cascades into the cells (C3/C4 areas), which have extract only. The gloveboxes (C5 areas) have air cascaded into them and are extract ventilation only.

BNFL carried out a significant programme of research into the airflows associated with the access facilities to such rooms, to establish both the correct velocity to provide maximum containment and also into the airflow patterns within glovebox cells. It was found that the arrangement of access facility used by BNFL can achieve a DF in excess of 10^3, cell to corridor. The results of this research have been incorporated into the design guidance for ventilation designers within BNFL.[8,9] In a new BNFL plant, the basic flow across an access facility into a plutonium cell would be 2700 m^3/hour. After this other factors have to be addressed, such as any heat removal there may be or dilution effect required. The throughput of air would be based on the actual needs and not an arbitrary figure of air change rate. If there were requirements that increased the flow over the 2700m^3/hour, this increased flow would be cascaded through the access facility.

If the room were 10m by 10m by 5m high with one access facility, the extract flow by the BNFL philosophy would be 2700 m^3/hour. If the ventilation rate had been determined using the AECP 1054 recommended air change rates from 1979 the extract flow rate could be as low as 2500m^3/hour or as high as 15,000m^3/hour. However, if the room were to be double the size (20m x 10m x 5m) and still have only one access facility, then by the BNFL philosophy, that access facility would only have the same minimum velocity criteria and hence the extract flow rate would still be 2700 m^3/hour, whereas using the 1979 air change rate method, the extract flow rate could range from 5,000m^3/hour to 30,000 m3/hour!

This was the basis for the design of BNFL's new generation of plants built during the 1980's an 1990's at Sellafield. The most reported of these facilities has to have been the THORP plant and the ventilation systems for that plant have been presented to previous DOE/NRC conferences. [10] The THORP plant discharges around 1.5 million m^3/hour and the average air change rate is 1.25/hour. Had the plant been built to the recommendations of the 1979 issue of AECP 1054 the discharge volumes would have been in excess of five times more! That is many times more ducting, fans, filters, dose to workers and public, as well as running costs! Multiply that by the number of plants BNFL has built at Sellafield in the past ten years and the figure becomes unimaginable. In the mid 1980's BNFL was spending in excess of £20 million/annum on electricity for fans the new plants could have easily more than doubled that, but the adoption of this new design approach to ventilation has ensured that this has not been the case.[11]

The proof of any new theory is in the application and BNFL has applied this new approach to containment and ventilation design to its new generation of plants and some of those plants are now fully operational with feed back information on their performance available. Again the most noticeable is THORP and the Plutonium Finishing Line of THORP has processed a significant quantity of plutonium nitrate into plutonium oxide and the operational corridors of that part of the plant have been maintained around the 3% DAC target level. (This is the corridors indicated in Figure 5).

Conclusion

Thus the basis for ventilation design that has been adopted by BNFL has been shown to produce smaller ventilation systems with lower demands for plantroom space. (By far the greatest capital cost element of the ventilation system is the building volume demanded for plantrooms and distribution of the ductwork around the plant.) The equipment required is smaller and there are significantly less active filters, which results in less solid radioactive waste production, which also results in less dose to the maintenance staff who change the filters. The discharges to the atmosphere are less and the safety of the plant in terms of potential spread of contamination and dose to the workers has been shown not to have been compromised. The aerial effluent discharges to atmosphere are also well within the license limits for the plant.

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