THE DESIGN OF VENTILATION FOR NUCLEAR PLANTS

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The paper begins by developing the concept of CONTAINMENT and describes how the ventilation system of a nuclear plant plays a major role in the provision of this CONTAINMENT and in ensuring that the plant can be operated safely.

It continues to describe the various demands that a nuclear plant places on the ventilation system and describes the types of areas that require ventilation.

The paper finally describes how BNFL Engineering Division have designed a new generation of reprocessing plants for Sellafield that have low air throughputs. The benefits of these low air throughputs are shown to be manifest in reduced aerial effluent discharges to the environment and reduced operating costs.

INTRODUCTION

Currently the cost of electricity to run fans at Sellafield is over £18.0 million each year. The heating requirements of the buildings at Sellafield use approximately 65% of the steam raised for the site. These facts, the escalating cost of energy, commercial economic pressures and an extensive investment programme for the 80's and 90's have forced British Nuclear Fuels Engineering Division to refine its basis of design for the ventilation of buildings containing radioactive materials.

Refinement of the basis of design requires the ventilation philosophy of the nuclear plant to be examined closely to define precisely the requirements of the plant. The requirements are then defined in terms of what is necessary rather than general allowances. This leads to more cost-effective designs.

The benefits of cost-effective designs of ventilation systems in the nuclear industry are manifest in two areas. Firstly in the reduction in aerial effluent discharges to the enviornment and second the reduction in operating costs of the plant in question, both from a financial stand point and that of radiation exposure of the operators.

CONTAINMENT

A primary requirement for any nuclear plant, irrespective of function, must be the prevention of loss of radioactive material to the environment. This ability to retain material is known as CONTAINMENT.

The ideal containment would be a sealed box, such as a fully welded metal can, and certain stores and repositaries do hold material in this way. However, in the reprocessing of nuclear fuel the need to gain access to the material means that the sealed box is punctured to allow for service feeds, process functions and waste removal. These penetrations are considered to be weak points in the containment and are subsequently backed up by a further barrier.

The second barrier usually called a cell, cave or glovebox also requires penetrations, which are again enclosed in a local barrier. This is known as the multi-barrier philosophy, with successive barriers enclosing increasingly cleaner zones until the naturally occuring levels of the environment are reached. The number of barriers required is dependant upon the efficiency of each barrier and the nature and number of penetrations.

The efficiency of a barrier is dependent upon its construction. This in turn is dependent upon such requirements as biological shielding, seismic integrity, ease of construction and cost. In the reprocessing industry large quantities of reinforced concrete are used.

Nuclear plants are built with a design life of thirty years, and concrete with pipe penetrations will not provide 100% efficient containment throughout that time. Hence, the physical containment is reinforced using ventilation.

The design aims of a combined Containment and Ventilation system are:-

- the prevention of loss of radioactive material under normal and incident conditions;
- the control of atmospheres within process vessels;
- the provision of a safe working environment;
- to protect operators from airborne contamination;
- to minimise aerial effluent discharges to the atmosphere;
- to comply with the statutory requirements of the UK and European legislation.

Air flowing from the lesser to the greater area of risk minimises the potential spread of radioactive material across the zone boundary. This air flow is induced through engineered inlets and adventitious routes by holding the higher potential area at a depression relative to the lesser potential area. This gives, in theory, multiple concentric zones with an increasing depression from atmosphere to the areas of highest radioactivity at the centre of the building where there is an extract, Figure One.

This layout is impractical and would not be used on a modern nuclear plant. It is a design aim to minimise the volume of the building affected by any incident or leak and hence, the divide and conquer rule is applied. Each individual potential source of risk is locally contained and hence the layout looks more like Figure Two. However the depression gradient requirement remains an overriding basis of design for the nuclear plant ventilation system.

Thus, the design of the ventilation system for a nuclear plant is dictated by the building layout and the maintenance of boundaries, ie. containment. All other requirements that modern industrial buildings place on the ventilation system have to be satisfied within the constraints of the nuclear plant.

VENTILATION REQUIREMENTS

The requirements for the ventilation system of a nuclear plant are:

a. Winter Heating/Summer Cooling

b. Process Cooling

c. Process Offgas Control

d. Clean Up of Aerial Effluent Discharges

a. Winter Heating/Summer Cooling

An important design aim for nuclear plants is to reduce to a minimum the amount of plant and equipment within the active area and hence to reduce operator and maintenance radiation dose uptake. Most plants utilise the ventilation system as warm air heating. This removes the need for heating units within the active zone and the heating coils remain clean as they are in the fresh air supply system ducting. Similarly, the summer cooling requirements of the plant are satisfied using the ventilation system. The aim is to use "Fresh Air Free Cooling", but the need to reduce plant fresh air throughput is increasingly introducing chilling on building supplies.

The cascade system generated by the depression gradient and cross boundary air flows can present difficulties both in winter and summer. In the winter the outer zones of the building are heated to offset fabric heat losses, but the rooms further along the cascade must not overheat. In summer as the air cascades from room to room the cooling capacity is reduced and allowable maximum temperatures become critical.

b. <u>Process Cooling</u>

An inherent feature of radioactive material is decay heat, the heat emitted as the material undergoes radioactive decay. The amount of heat given off is dependent upon the radionuclides present and the quantity of material. Another inherent feature is the requirement for biological shielding to protect the operators. Thus a heat emitting substance is contained within a shielded enclosure, normally constructed from reinforced concrete, which acts as an insulator, causing a significant temperature rise and the need for cooling. Where mechanical handling of radioactive materials is carried out remotely, the thick concrete walls have lead glass windows and to allow even a reasonable level of visibility within the containment very high lighting levels are required. This adds to the temperature rise and the need for cooling. In the chemical reprocessing of nuclear fuel large quantities of steam are used to heat acid for the dissolution of fuel elements and in the evaporation of liquors to reduce volume of both product and waste. This again adds to the need for cooling.

c. <u>Process Ventilation</u>

Water is used on reprocessing plants as a shielding material and aqueous solutions form a large part of the process chemistry. The effect of radiation on water is called radiolysis and this releases the hydrogen from the oxygen. The oxygen is readily combined with other chemicals leaving the hydrogen as a free gas. Thus hydrogen is an ever present potential on nuclear plants and flammable gas dilution is another requirement of the ventilation system.
The use of large quantities of nitric acid in the reprocessing cycle gives rise to the release of NOx and acid fumes, which again are handled by the ventilation system.

d. <u>Clean Up of Aerial Effluent Discharges</u>

All the air moved by a ventilation system, other than in a total recirculation system, has to be discharged to atmosphere. It should be noted that recirculation systems are not preferred on nuclear plants as they can lead to increased concentrations of airborne activity in the area recirculated. Once through systems are the norm. The air extracted from a nuclear plant carries to a greater or lesser extent, radioactive or chemical contamination. A nuclear plant requires a license from the regulatory bodies to operate, and part of the license limits the amounts of aerial and liquid effluents that can be discharged to the environment in terms of total quantities of radionuclides, rather than concentrations in air, that can be released over various periods from days to a year.

The clean up systems used on nuclear plants are usually Hepa filters. For chemical process extract systems wetted scrubbers and columns may also be used. A typical extract system would have two stages of HEPA filtration and have a fan duty of 6.0K pa. For a fixed quantity discharge limit the more air moved, the bigger the cleanup system and the fan pumping power necessary. Thus there is pressure to reduce the plant air throughput both from the point of view of radiological discharges to the atmosphere, generation of contaminated solid waste such as filters, and energy costs.

<u>RADIOLOGICAL CONSIDERATIONS</u>

The International Commission for Radiological Protection (ICRP) issue allowable annual limits for radiation dose uptake[1] and these are 50 millisieverts for a radiologically classified worker and 5 millisieverts for a member of the public. The BNFL target exposure for a radiation worker is in fact 20 millisieverts. In addition

ICRP publish annual limits of intake (ALI) by inhalation[2]. Using ALI and assuming a working year of 2000 hours, an air concentration can be established, which if inhaled for one working year would result in the above whole body dose of 50 millisieverts by inhalation alone. This concentration is known as the Derived Air Concentration (DAC).

A comparison of a typical radioactive material limit for a radiological worker and a non-radioactive limit would be:

Plutonium Limit	10^{-9} mgm/m^3 in air
Phosgene Limit	10^{-1} mgm/m^3 in air

The plutonium limit can be expressed as one particle of 0.6 um diameter per cubic meter of air.

RADIOLOGICAL ZONING

Once the building layout has been developed and the physical containment boundaries established, the rooms and areas of the building are radiologically classified. Each area is assessed in terms of airborne and surface contamination levels and then in terms of radiation levels. The assessment places each area into one of the radiological classifications or zones. This method defines each area in terms of radiological hazard potential to the occupant and allows the entry/exit control procedure to be developed. In the BNFL classification of zones system there are five zones (see Figure Three).

BASIS OF VENTILATION DESIGNS

BNFL has undertaken a massive investment programme at Sellafield throughout the 80's and it continues into the 9O's. The amount of investment in new plants and refurbishments is equivalent to £1.0 million per day for ten years. With this rate of expenditure even the smallest part of a percentage saving can reap enormous sums. With this in mind the basis of design of ventilation for nuclear reprocessing plants has been refined.

The first requirement is to establish the exact needs of the plants and define the design aims of the ventilation system. This has been broadly spelt out above. The next requirement is to undertake the ventilation design to meet the identified needs of a building, justifying at every stage why air is being moved.
Commercial designs of H&V are undertaken using the CIBSE guide as reference, particularly section B2, Table B2.2[3]. A similar guide exists for the nuclear industry in AECP 1054[4]. The 1979 issue of AECP 1054[4] gives typical air change rate information as shown in Figure Four. The trend over recent years towards reducing the air throughputs on nuclear plants is reflected in the April 1989 issue of ACEP 1054[5] (see Figure Four).

Taking, as an example of these new generation of plants at Sellafield, the Second Encapsulation Plant (EP II), the impact of the changes in ventilation design can be assessed. The schematic ventilation flow diagram for EP II is given in Figure Five.

A comparison of the air throughputs based upon the recommendations of ACEP 1054[4] and the actual design is given in Figure Six. The reduction is the result of implementing the scientific design approach outlined below rather than using general ventilation allowances such as air change rates. The difference will be even more marked for plants such as the Thermal Oxide Reprocessing Plant (THORP) which has a building volume of approximately 1.0 million m^3 and an average air change only 1.25 per hour.

This dramatic reduction in air change rates has been achieved by adopting a new design approach where the actual ventilation requirements of each plant item, electrical item and planned occupancy are identified and these requirements addressed on an individual basis rather than using traditional air change rates. The general outline of this approach is given below;

a) Assess the proposed building layout and zone the areas both radiologically (as described earlier) and with a view to the process operations (eg. chemical considerations). This defines the boundaries between zones of differing potential risk and also identifies the direction of airflows (ie. from lesser to higher potentials).

b) Establish the necessary containment flows. This may be a minimum flowrate across an entry door, or the removal of in leakage caused by holding an area at a prescribed depression.

c) Identify the need for and quantify the amount of any dilution air flows necessary for the limitation of concentrations of toxic and/or radioactive chemicals or explosive gas.

d) Identify the heat loads within the various zones and ensure that the air throughput is adequate to achieve the necessary environmental conditions, dictated by the occupants and/or the process.

e) Overview the whole design to ensure that the various airflows identified in a) to d) are balanced. This may require that the throughput of one room be increased in order that the needs of another room further along a cascade may be met.

CONCLUSIONS

"Use of old rules of thumb and design-by-catalogue engineering are improsing high energy costs and actual discomfort in many modern factories." This is a quote from the CIBSE journal[6] and is a point of view that reinforces the work undertaken within BNFL over the last ten years and presented in this paper.

The reductions in air throughputs shown in Figure Six are self evident and the design approach that brought them about has been applied to other plants also. THORP and EPII, along with other waste management plants at Sellafield are still under construction and the success of these particular designs will only be fully realised once they are operational. However, plants such as Finishing Line Five, the Vitrification Plant and the Receipt and Storage Facility for THORP have been designed using the same approach and these plants are extremely successful. This design approach has not only been successful in reducing the air throughputs, but by focusing the attention of the designers on the areas that significantly affect containment and environmental comfort, better standards are being achieved. The nett results of these reductions in air flow through nuclear plants are;

a) Reduced discharges to the environment. Although a particular site license alocates a plant an allowable aerial discharge, it is BNFL policy to comply with the ALARA (As Low As REASONABLY Achievable) principle.

b) Reduced size of clean-up plant, with the associated reduction in solid and liquid radioactive wastes arisings. Reduction of waste arisings leads to significant economic savings in nuclear plants.

c) Reduction of fan size and running costs. BNFL is looking to reduce the costs of reprocessing and waste management of nuclear fuel, operating costs along with capital costs are being increasingly scrutinised.

d) Reduced space heating costs. The majority of buildings use steam as their primary heating medium. The present source of steam for Sellafield is Calder Hall power station. This has a limited life and a new steam generating plant will be necessary in the next century. A reduction in steam usage would reduce the size of replacement plant or allow more energy to be sold externally.

e) By reducing the amount of equipment (particularly filters) in the active areas, the associated maintenance radiation dose uptake is reduced. This has helped to counteract the general trend of increased maintenance time on more remotely operated radioactive material handling plants designed to reduce the number of production radiation workers.

The reprocessing buildings currently being constructed and commissioned at Sellafield will take the nuclear industry into the next century. This new generation of plants have lower discharges to the environment lower dose uptake to the operations and are safe and economic to operate. They are the product of the experience gained over many years from operating the existing Sellafield plants. This mix of operating experience and design expertise is unique in the UK nuclear industry, to BNFL. The lessons to be learned from this exercise are not restricted to BNFL, nor the nuclear industry, but are applicable to the whole of the building services field. The establishment of the precise ventilation requirements of a particular plant and the clear definition of the design aims are essential prior to the commencement of design, if energy consumption is to be reduced and the assessment of ventilation plant maximised, whilst still meeting the requirements of the client.

REFERENCES

1. ICRP, Recommendtions of the International Commission on Radiological Protection, Publication 26, 1977.

2. ICRP, Recommendations of the International Commission on Radiological Protection, Publication 30, 1989

3. CIBSE Guide B2 Ventilation and Air Conditioning (Requirements), 1976

4 UKAEA, Ventilation of Radioactive Areas, AECP 1054, 1979

5. UKAEA, Ventilation of Radioactive Areas, AECP 1054, 1989 (Provisional issue for comment)

6. S Ashley, Beware Factory Overheating, CIBS Journal, Vol 5, Sept 1990, Page 36

LIST OF ILLUSTRATIONS

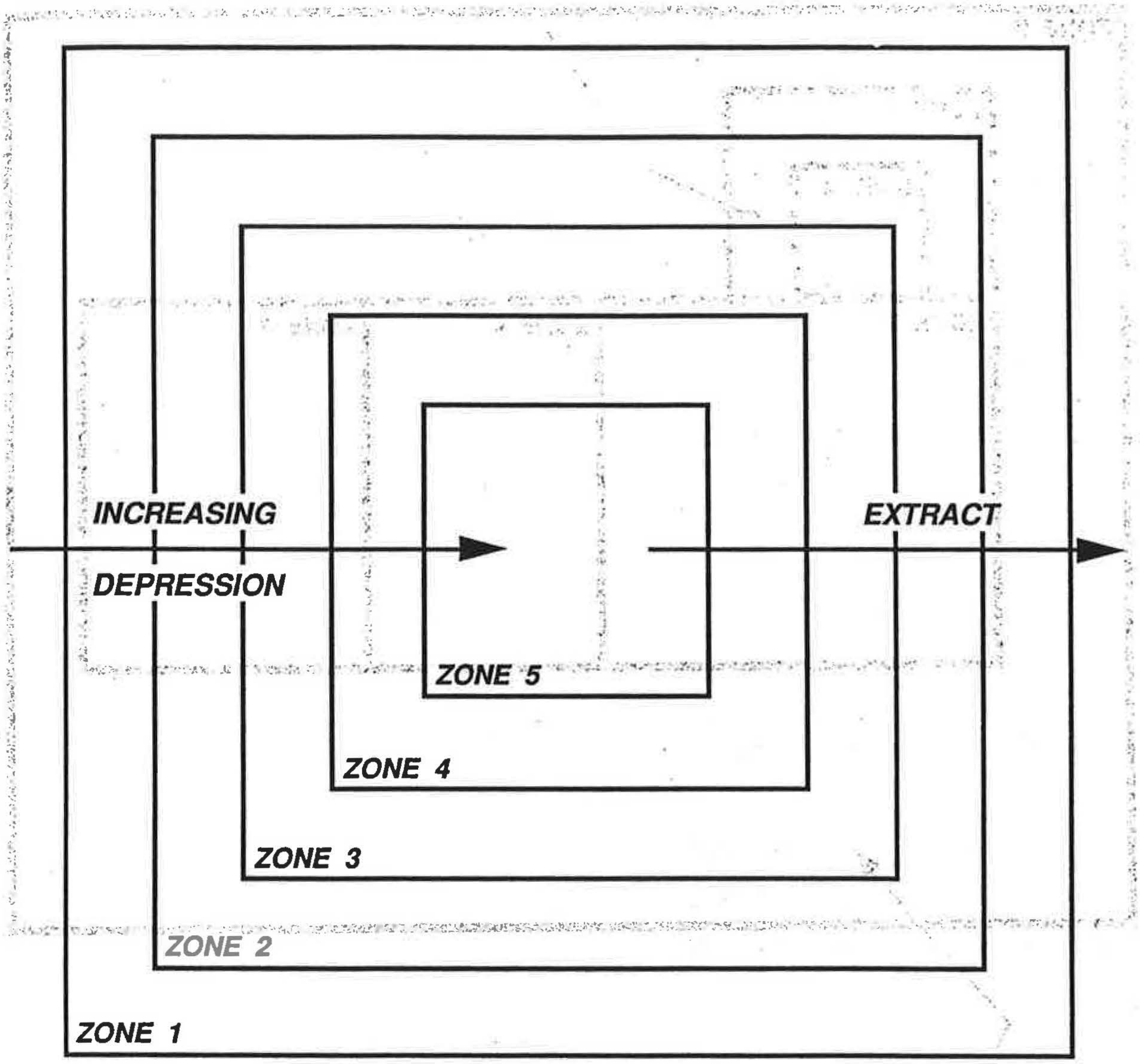

FIGURE ONE : IDEALISED CONTAINMENT LAYOUT.

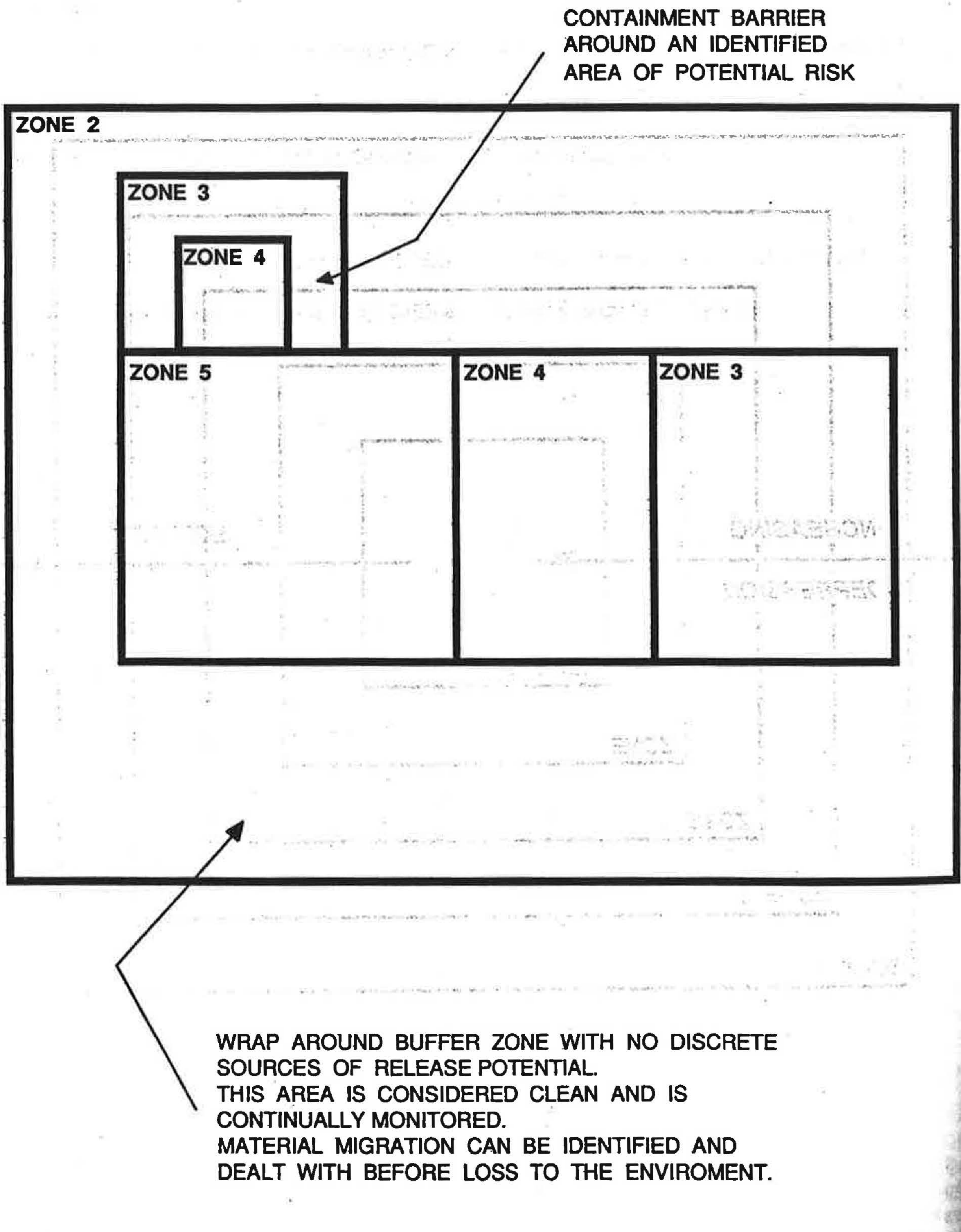

FIGURE TWO : TYPICAL BUILDING LAYOUT
SHOWING HOW CONTAINMENT IS ACHIEVED.

ZONE	TARGET AVERAGE LEVEL OF CONTAMINATION IN AIR	TYPICAL ROOMS AND/OR TYPES OF OPERATION	COMMENTS
1	NATURALLY OCCURING BACKGROUND ONLY. < 1 % DAC	OFFICE BLOCKS MANAGEMENT CENTRES CANTEENS, ETC.	THE MANAGEMENT CENTRES AND OFFICE BLOCKS OF THE LATEST BNFL PLANTS WOULD NOT LOOK OUT OF PLACE IN THE CENTRE OF LONDON IN TERMS OF ARCHITECTURE AND SERVICES PROVIDED
2	1 TO 3 % DAC	OPERATING AREAS ON-PLANT OFFICES WORKSHOPS, ETC	NORMALLY ADJACENT TO EXTERNAL SKIN OF BUILDING AND REQUIRE HEATING IN WINTER. WORKERS CAN REMAIN HERE FOR 2000 HRS/ YEAR WITHOUT EXCEEDING THEIR WHOLE BODY DOSE TARGET HIGH HEAT GAINS FROM EQUIPMENT, MOTORS, ETC. AREA HELD AT A NOMINAL DEPRESSION RELATATIVE TO ATMOSPHERE.
3	10 % DAC	MAINTENANCE AREAS LIQUID SAMPLING FLASKING AND POSTING OPERATIONS	PERSONNEL WOULD CNANGE THEIR CLOTHING AND MAY WEAR A RESPIRATOR TO MINIMISE SPREAD OF CONTAMINATION THIS ZONE IS EXTRACT ONLY, WITH CASCADED SUPPLY. AREA HELD AT A NOMINAL DEPRESSION RELATIVE TO ZONE2
4	100 % DAC	MAINTENANCE AREAS	FULL CLOTHING CHANGE WITH RESPIRATOR, MAY WEAR A PVC SUIT AND HAVE INDEPENDENT BREATHING AIR. ENTRY INTO THESE AREAS VERY TIME DEPENDENT. EXTRACT ONLY, WITH CASCADE SUPPLY AREA HELDAT A NOMINAL DEPRESSION RELATIVE TO ZONE 3
5	> 100 % DAC	PRIMARY CONTAINMENT PROCESS VESSELS ETC.	RADIATION AND CONTAMINATION LEVELS ARE SUCH THAT EXPOSURE IS VERY LIMITED AND PROTECTIVE CLOTHING IS ESSENTIAL, IF ENTRY IS POSSIBLE AT ALL. EXTRACT ONLY, CASCADE SUPPLY THROUGH HEPA FILTERS. AREA HELD AT AN APPRECIABLE DEPRESSION TO PROVIDE DRIVING FORCE FOR CASCADE FLOW, HENCE APPRECIABLE INLEAKAGE.

FIGURE THREE RADIOLOGICAL ZONES

COMPARTMENT	TYPICAL AIR CHANGES PER HOUR AECP 1054: 1979	ZONE COLOUR CODE	TYPICAL AIR CHANGES PER HOUR AECP 1054: 1989
Change Rooms	4 to 5	White, Green or Amber	4 to 5
Normally Clean Air Corridors	5	Green	1 to 2
Normally Non-Active Rooms	5	Green	1 to 2
Controlled Areas of Low Potential Hazard	5	Green	2
Controlled Areas of High Potential Hazard	10	Green	5 to 10
Maintenance Areas to to Primary Containments of Low Risk Process Plants	5 to 10	Amber	1 to 5
Maintenance Areas to Primary Containments of High Risk Process Plants	30	Amber	10
Primary Containments (Gloveboxes, Cells and Caves)	2 to 30 depends entirely on process and hazards	Red	1 to 30 depends entirely on process and hazards

NOTE: THE COMPARISON OF THE COLOUR CODING TO THE BNFL ZONING IS AS FOLLOWS

WHITE	-	ZONE 1
GREEN	-	ZONE 2
AMBER	-	ZONES 3 & 4
RED	-	ZONE 5

FIGURE FOUR : GUIDE TO AIR CHANGES ACEP 1054

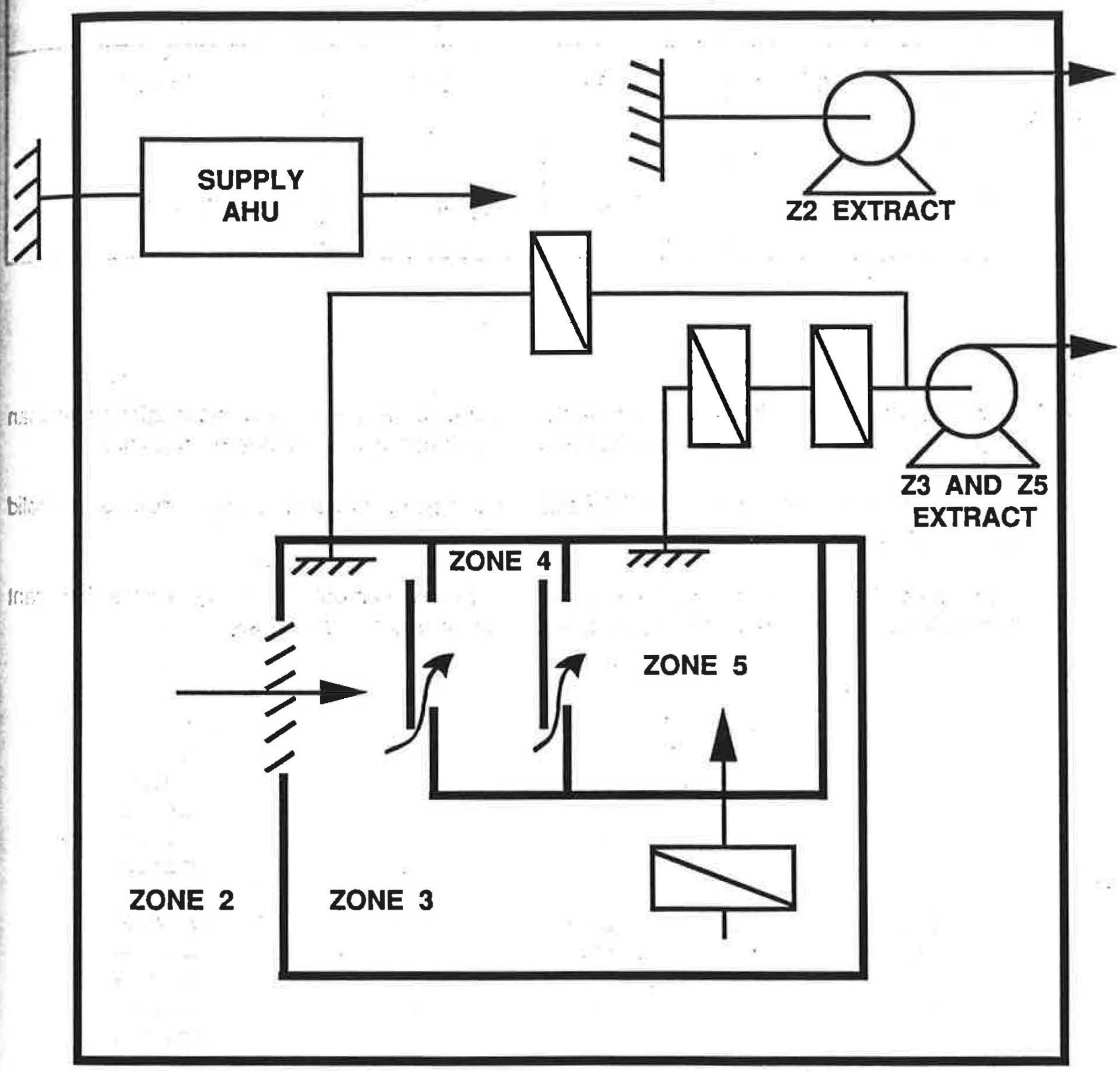

FIGURE FIVE : EPII SCHEMATIC VENTILATION FLOW DIAGRAM.

COMPARTMENT	ZONES 1&2 m^3/hr	ZONE 3 m^3/hr	ZONES 4&5 m^3/hr	TOTAL THROUGHPUT OF PLANT m3/hr
DESIGN BASED ON AECP 1054 (1979)	701,225	57,625	115,570	874,420
ACTUAL DESIGN	158,252	48,841	59,400	266,493

NOTE: Zones 1 and 2 are essentially clean areas, catering for specific requirements for ventilation rather than providing general air change ratio results in savings on heating and fan energy consumption.

Zone 3 extract has a single stage of HEPA filtration and savings are made in active discharges/solid waste and fan power.

Zone 5 extract has two stages of HEPA filtration because of the amount of activity. A very significant reduction has been achieved here in discharges, waste production and costs.

FIGURE SIX : COMPARISON OF AIR THROUGHPUTS