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HAZARDS ANALYSIS OF FUEL HANDLING FACILITIES*

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ABSTRACT

Accidental releases of radioactive material at the Oak Ridge National Laboratory during the Fall of 1959 resulted in the establishment of building and ventilation design criteria and the requirement for a hazards evaluation for those facilities which contain or handle radioactive materials of physiological hazard greater than that equivalent to one gram of Pu-239.

A quantitative method for estimating the hazards associated with the maximum credible accident in a radiochemical facility has been developed. The maximum credible accidents in such facilities are chemical or nuclear explosions which disperse radioactive aerosol and gases into ventilation streams which exhaust to the atmosphere. Approximate physical properties of these aerosols and gases have been combined with the efficiency of ventilation cleanup devices and meteorological correlations to evaluate the hazard to the environment.

Methods of hazards evaluation have been applied to ORNL radiochemical facilities to establish necessary containment and ventilation criteria, to determine the more probable and important mechanisms of activity releases, and to demonstrate that acceptably low personnel exposure and ground contamination would result from a maximum credible accident in each facility after modification to meet the new containment criteria.

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1.0 INTRODUCTION

Accidental releases of radioactive material at the Oak Ridge National Laboratory during the Fall of 1959 resulted in the establishment of building and ventilation design criteria and the necessity for a hazards evaluation for those facilities which contain or handle radioactive materials of significant physiological hazard.

In the past, nuclear fuel handling facilities have never been given as serious a hazards analysis during design stage as have nuclear reactors. A comprehensive hazards survey is required of all reactor concepts before AEC approval is granted. Because of accidental releases, methods of hazards evaluation have been developed at ORNL to establish necessary containment and ventilation criteria, to determine the more probable and important mechanisms of activity releases, and to demonstrate that acceptably low personnel exposure and ground contamination would result from a maximum credible accident in each facility after modifications to meet new containment criteria.

Such building changes were considered advisable to prevent jeopardizing laboratory personnel and other laboratory facilities in the event of such an accident. One requirement of these new criteria was that secondary building containment would be placed around all process cells which could otherwise leak significant activity directly to the environment in the event of an accident. It was specified that these criteria, along with the necessity of a reactor-type hazards evaluation, would apply to those facilities which contain radioactive material of physiological hazard greater than that equivalent to 1 g of Pu-239.

The hazards associated with the operation of a chemical processing or fuel handling facility may be as great as or greater than those associated with a reactor, measured in terms of the total fission-product inventory, the activity released in a nuclear excursion, or the amounts of activity that could be released by chemical reactions or mechanical failures. Maximum credible accidents in such radiochemical facilities are chemical or nuclear explosions which disperse radioactive aerosols or gases into ventilation streams which exhaust to the atmosphere. A realistic hazards evaluation must take into consideration the physical properties of the radioactive gas or aerosol that is formed and the

efficiency of air cleanup devices for removal of these radioactive materials prior to discharge to the atmosphere.

We have attempted to make such an evaluation of ORNL radiochemical facilities by using properties of aerosols and gases that are found in the literature. The studies, in general, have demonstrated the adequacy of secondary containment and present air cleanup devices but have pointed up the necessity for reliability of these devices, particularly filters, and have indicated areas in which further experimental work is required.

2.0 THE BUILDING 3019 EVAPORATOR EXPLOSION

The need for adequate primary and secondary containment was acutely demonstrated in the Bldg. 3019 evaporator explosion. A chemical explosion occurred in an evaporator complex that contained approximately 1500 g of plutonium as solution, precipitate, and scale and scattered 600 mg of the plutonium through a cell door, blown open by the explosion, directly to the environment. Although no personnel were injured or received an intolerable radiation dose during the accident, a portion of ORNL was significantly contaminated. In addition, the operating areas of the facility were contaminated by air flow through open pipe chases and other penetrations which communicated through the cell wall.

A post-explosion examination of the facility revealed that the loss of plutonium to the environment would have been maintained within acceptable limits if (1) the door had not been blown open, (2) the penetrations through the cell wall had been minimized, and (3) the entire cell bank had been contained within a building. The release of plutonium through the existing cell and vessel ventilation filters was determined to be negligible.

The cell ventilation cleanup system, consisting of pocket roughing filters backed up by absolute filters, collected approximately 1.5 g of plutonium and there was no measurable contamination on the exhaust side of the absolute filters. Examination of the roughing and absolute filters indicated that the roughing filters contained 98.8% of the plutonium and that the particles collected by the filters had a mass mean particle size of 0.67 μ with a standard deviation of 2.3.

3.0 CONTAINMENT CRITERIA FOR A PROJECTED RADIOCHEMICAL FACILITY

A schematic diagram of a radiochemical facility which meets the minimum recommended design criteria is shown in Fig. 1. The diagram depicts a typical vessel in a process cell which is completely surrounded by a building. The cell, which constitutes primary containment, is capable of withstanding the blast effects of the maximum credible explosion without rupture and permits only a minimum leakage of radioactive material to the secondary containment shell, the building structure. Other criteria for the process vessels, cells, and buildings are:

(1) Filters are located such that they will be protected from the maximum credible explosion.

(2) Process vessels are maintained at a vacuum of at least 2 in. w.g. during normal operation by a vessel off-gas system which passes through a local scrubber and filter system as well as a plant treatment system before being exhausted to a stack.

(3) A cell is maintained at a vacuum of at least 1 in. w.g. during normal operation. The cell ventilation exhaust capacity is at least equivalent to 1/10 of a cell volume per minute. The air intake to the cell is through a roughing filter and check valve. The cell exhaust passes to a cell ventilation manifold, roughing and absolute filters, and from thence to the stack. The cell is sealed so that the leak rate is less than or equal to 1/100 of a cell volume per minute at 2 in. w.g. differential pressure.

(4) The building is maintained at a few hundredths of an inch w.g. vacuum during normal operation. The intake is through dust filters and check valves. The exhaust is through roughing and absolute filters located at the roof of the building or at the stack. The cell ventilation blower must have sufficient capacity to evacuate the building to 0.3 in. w.g. vacuum in 20 sec by closing the intake. The building is sealed so that a leak rate of no more than 6×10^{-3} building volume per minute will occur at a differential pressure of 0.3 in. w.g. This criterion is included to ensure that the building vacuum will be capable of balancing a vacuum of 0.3 in. w.g. that could be created on the lee side of a building by a 30-mile/hr wind. At ORNL it is pertinent to assume that winds of speed greater than 30 miles/hr are sufficiently rare as to be incredible.

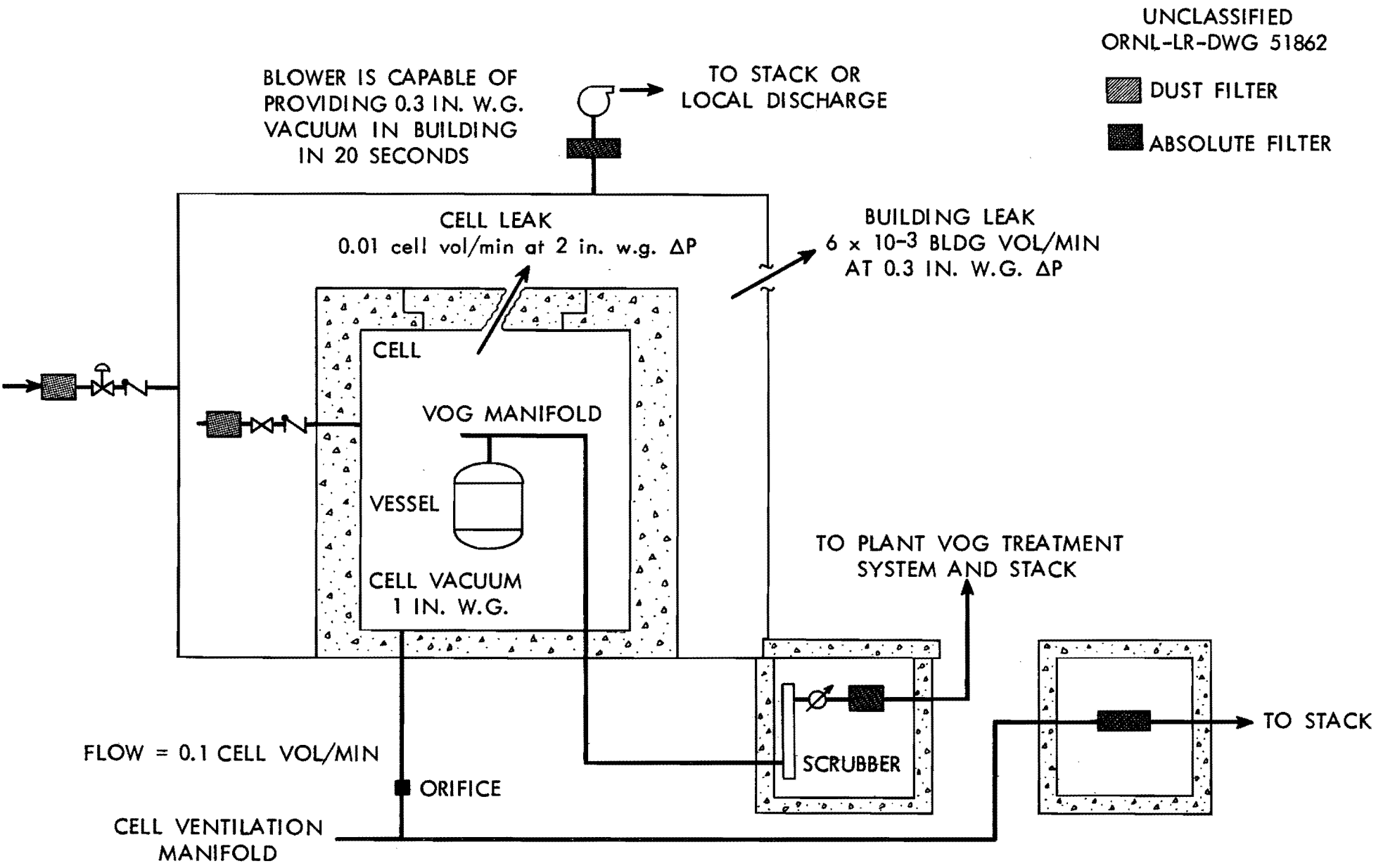

Fig. 1. Schematic diagram of minimum containment provisions for radiochemical facilities.

4.0 TYPES OF DISPERSIVE ACCIDENTS

The most serious accidents that may credibly occur in large radiochemical facilities are chemical and nuclear explosions which rupture vessels filled with radioactive process solutions or solids. It is our current belief that a radiochemical facility can be designed so that the maximum credible explosion will correspond in gas production and blast effects to that of 3 lb of TNT. Three pounds of TNT liberates approximately 5700 Btu of energy, generates approximately 100 ft^3 of hot gases, and creates a shock wave that has a pressure of approximately 800 lb/ft^2 and an energy of approximately 230 $ft\text{-}lb/ft^2$ at a distance of 15 ft. Thick concrete cells of the type used in ORNL radiochemical facilities can withstand such explosive effects without rupture.

Examples of the types of explosions that may credibly occur in a radiochemical facility of special design and simulate the gas production and/or the blast effects of the reference TNT detonation are the detonation of 10 ft^3 of a H_2-air mixture, the explosion of several pounds of a nitrated organic material, and a single nuclear burst of the order of 10^{18} fissions. Our studies indicate that the initial and maximum nuclear burst in vessels of the size used at ORNL will be of the order of 10^{18} fissions. A maximum credible accident will occur if the vessel is ruptured during this maximum burst, thus terminating the reaction; the accident would have less serious consequences if the vessel contains the excursion and the reaction recurs with 10^{19} to 10^{20} or more fissions until it is shut down by other means.

5.0 EFFECTS OF DISPERSIVE ACCIDENTS

The effects of the maximum chemical explosion are that an aerosol of the radioactive material would be formed in the cell air and a small fraction would reach the environment through the vessel off-gas system and cell ventilation system and through successive leaks from the cell and from the building. The maximum nuclear burst would disperse new gaseous fission products and an aerosol composed of new nonvolatile fission products and the original radioactive material. Another effect of the maximum nuclear burst is that operating personnel would receive prompt neutron and gamma radiation through the shield. The maximum

integrated dose through a 5-ft-thick concrete wall before personnel evacuate the facility would be less than 1 rem, however. The effects of direct radiation from a criticality incident are presented in Table I.

5.1 Gaseous Fission Products

The gaseous fission products which could be released in a nuclear excursion are the isotopes of xenon, krypton, bromine, and iodine. It is usually appropriate to assume that 99% of the bromine and iodine are removed in a vessel off-gas system consisting of scrubbers and absolute filters. It has been found that the isotopes with half-lives of the order of 1-10 min are controlling in downwind dose calculations. The maximum permissible concentrations of these isotopes are rather large, since they constitute only external radiation hazards; they make up for the higher permissible concentrations, however, because of their greater activity.

5.2 Radioactive Aerosols

The aerosol that would be dispersed in cell air by the maximum credible accident would consist of a radioactive solution, solid particles, or smoke. The solution aerosol will be emphasized, since more information is available on this type and most of the ORNL facilities are of the wet chemical type. Smokes and dusts may be evaluated by an analogous procedure, provided their properties are known or are assumed.

The physical properties of aerosols are such as to restrict very effectively the escape of radioactive particles to the environment. This is seen commonly in practice, since through the use of appropriate deentrainment mechanisms the condensate from the evaporation of a radioactive solution may be made to contain only 10^{-4} to 10^{-6} of the activity of the solution. Gravitational settling is often sufficient to restrict an aerosol concentration; we have been able to show this by the approximate correlation (Fig. 2) of the solution concentration in air or vapor arising from cooling towers, evaporators, and air-sparged vessels.

In order to evaluate the release of aerosols from a cell, we must be able to ascribe removal efficiencies to filters and to cracks in cell walls. For superficial velocities less than approximately 0.15 ft/sec, it has been found that an aerosol formed by vigorous mixing of a solution with air is metastable and has a concentration of the order of 10 mg/m^3. This metastable concentration is approximately equivalent to fog, which

TABLE I

THE PROMPT NEUTRON AND GAMMA DOSE AT THE OUTSIDE OF A NORMAL CONCRETE SHIELD FROM A NUCLEAR REACTION OF 10^{18} FISSIONS

CONCRETE SHIELD THICKNESS, FT	DOSE AT OUTSIDE OF SHIELD, REM	
	METAL NUCLEAR REACTION	NUCLEAR REACTION IN AQUEOUS SOLUTION
0 (2' AIR)		98,000
1	88,000	5,200
3	317	23
4	17	1.9
5	0.96	0.14
6	0.06	0.012

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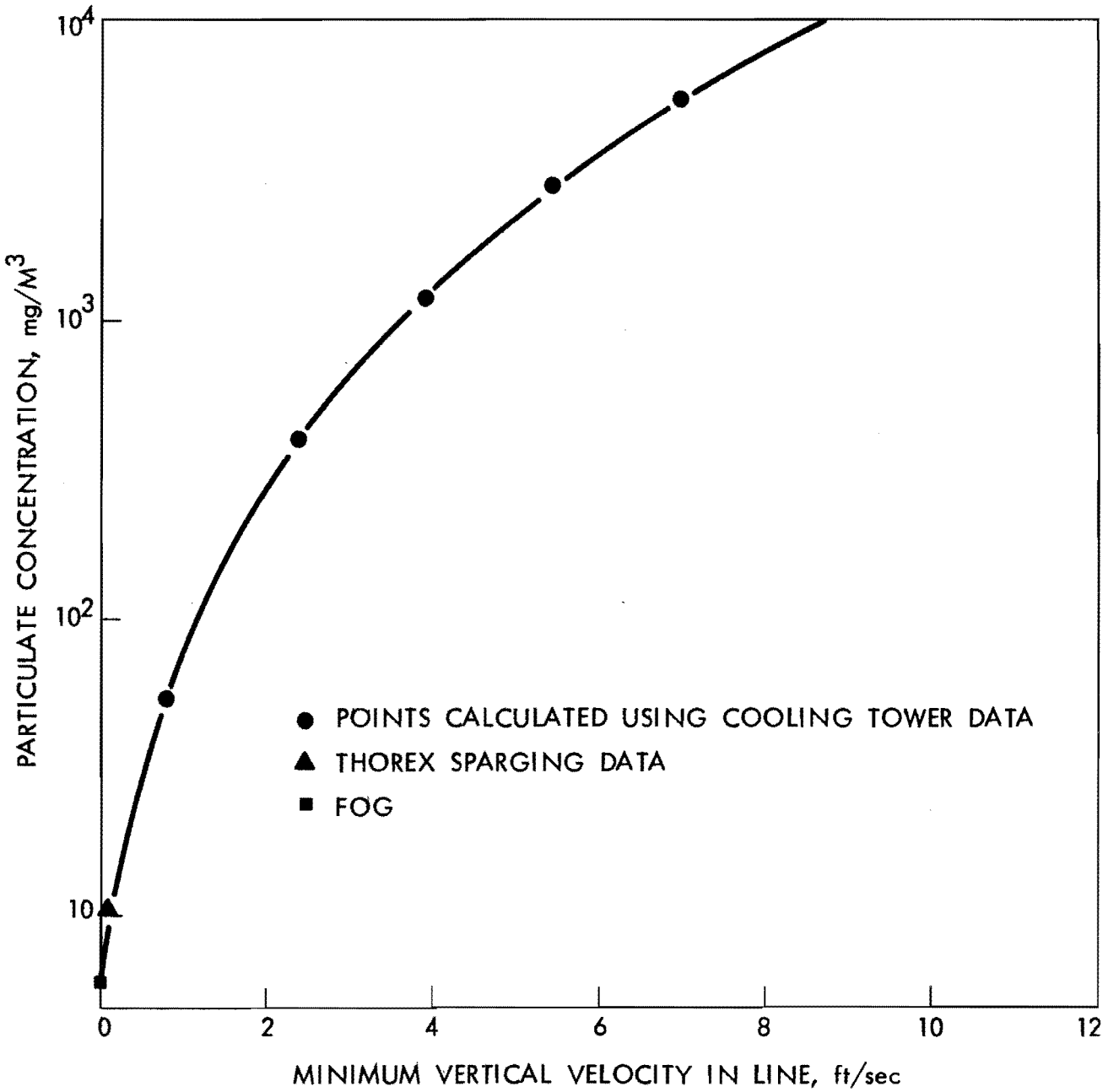

Fig. 2. The effect of minimum superficial velocity in an off-gas line on the concentration of liquid solution particles resulting from very vigorous mixing of a solution with air. (solution density = 1 g/cc)

has a concentration of approximately 10 mg/m^3 and a particle size of approximately 10 μ. For orientational purposes a 1-in./hr rain with mass mean particle size of 3000 μ has a concentration of 1000 mg/m^3. At ORNL the particle size distribution of the metastable aerosol in a ventilation stream downstream from the source has consistently been found to have the particle size distribution shown in Fig. 3. Another piece of relevant information reported by Garner in Transactions of the Institution of Chemical Engineers[1] is that the weight distribution of particles smaller than 10-20 μ will be fairly constant, even if there is gross entrainment of larger droplets. The knowledge that this distribution is fairly constant and constitutes approximately 10 mg/m^3 may be used to estimate the approximate concentration of particles smaller than a given size, even in an air stream which is very concentrated with liquid droplets. Practically, it is possible to assign efficiencies to an absolute filter and calculate the effluent concentration.

The following efficiencies were conservatively assigned to an absolute filter: 100% for particles greater than 5 μ, 99.95% for particles between 5 and 0.3 μ, 95% for particles between 0.3 and 0.1 μ, and 87% for particles less than 0.1 μ. The filter efficiency for particles smaller than 0.1 μ is based on data obtained at Harvard.[2] Applying these efficiencies to the particle size distribution in Fig. 3, the effluent concentration of liquid aerosol from absolute filters is calculated to be 0.14 mg/m^3. Calculations indicate that it is appropriate to assume that the liquid particles in the aerosol have essentially the original solution composition. In many instances it is also appropriate to assume 0.14 mg/m^3 as the filter effluent concentration of heavy element dust. This would indicate a conservatively high penetration of dust even if a large fraction is smaller than 0.1 μ, since it has been observed that heavy element dust exists in relatively stable air at concentrations of only 0.1-1 mg/m^3. It must be assumed that filters are only 87% efficient in removing smoke, since smoke particles are predominantly in the range 0.05-0.1 μ.

In evaluating the concentration of aerosols in air that leaks from a cell, it is considered that the design leak rate of a typical cell is equivalent to a flow of 100 ft^3/min through a 5-in. diameter orifice. Cell cracks will not simulate a single orifice but will consist of many

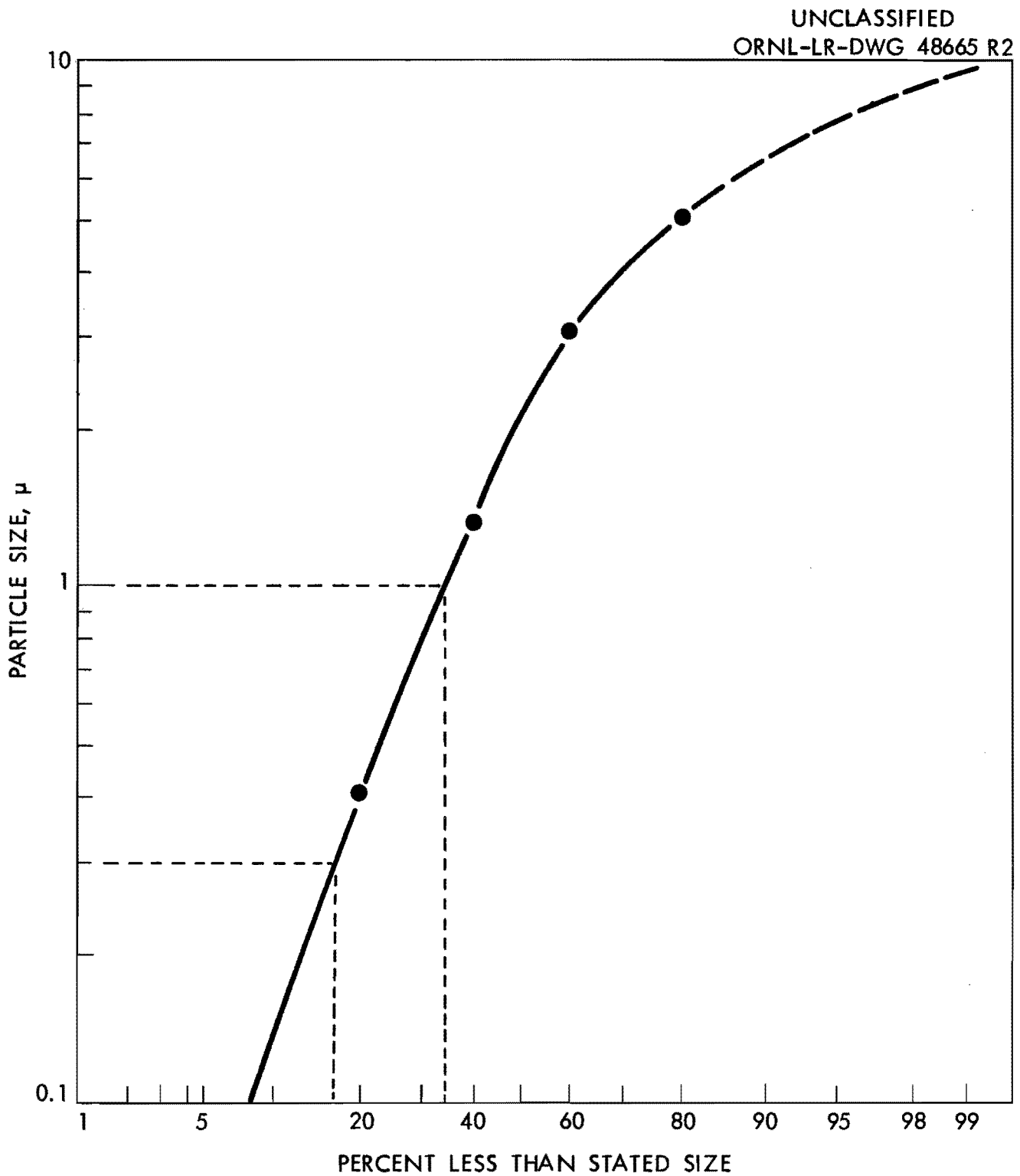

Fig. 3. The particle size distribution of a stable aerosol which has encountered several changes of direction in a pipeline.

small tortuous paths through 5 ft of concrete. The evaporator de-entrainment studies by Walsh and Schlea[3] at SRP indicate that a single right angle impingement of characteristics that we think indicate cell cracks will conservatively decrease any liquid aerosol concentration to 10 mg/m^3. Fine heavy element dust would be decreased to the order of 1 mg/m^3 and the concentration of smoke in leaked air would probably be no more than approximately 100 mg/m^3.

6.0 METHODS OF EVALUATION

The downwind radiation dose that would be received from the release of radioactive material from a stack or elevated source during unchanging weather conditions may be expressed as the product of the curies released, atmospheric dilution factor, and appropriate conversion factors divided by the mpc_a [4] (Fig. 4). The mpc_a of a radionuclide may be considered as that concentration of the radionuclide in air which will cause a total radiation dose of 100 mr for a 40-hr exposure. In the case of radionuclides that are predominantly internal radiation hazards, the bulk of the dose does not occur during the exposure but is accumulated over a lifetime, because of the presence of the radionuclide in the body. In the downwind exposure from a stack release calculation, we chose to use the so-called maximum average atmospheric dilution factor (Fig. 5), which is a measure of the maximum downwind ground concentration averaged over a time of the order of 0.5 hr and is an approximate measure of the maximum downwind ground concentration averaged over a several-minute period. We chose to evaluate the constant at a conservatively low wind speed of approximately 3 miles/hr, since this is the average ORNL wind speed and constitutes approximately the worst case. The plume rise of a stack causes the effective atmpsheric dilution to be greater at significantly lower wind speeds, and, of course, at very high wind speeds the dilution is significantly greater because of the extreme turbulence. We applied this concept to the calculation of the downwind internal and external dose arising from the gaseous fission products and from the aerosol; it implicitly assumes that the aerosol which escapes through an absolute filter is of such a small size that it behaves as a gas and is inhaled and exhaled as a gas. We think it is a fairly good approximation, since the aerosol particles that escape through an absolute filter are generally less than 0.1 μ in size and have negligible settling velocity.

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MAXIMUM AVERAGE GROUND DOSE RESULTING FROM RELEASE OF RADIOACTIVE MATERIAL FROM A STACK

$$\text{DOSE, rem} = D = \frac{Qk\,(0.1)\,(1.44)}{(\text{mpc})\,(1.44 \times 10^5)} = \frac{10^{-6}\,Qk}{(\text{mpc})}$$

Q = QUANTITY OF MATERIAL RELEASED, CURIES

(mpc) = CONCENTRATION, CURIES/M^3, OF RADIONUCLIDE IN AIR THAT CAUSES 0.1 rem OF RADIATION DOSE FOR 40 HOURS OF EXPOSURE (SEE NBS-69)

Fig. 4

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MAXIMUM AVERAGE ATMOSPHERIC DILUTION FACTOR AND DECAY TIME OF RADIONUCLIDES EN ROUTE TO THE GROUND

k = MAX. AVG. DILUTION FACTOR, SEC/M^3 = $\frac{2}{\pi e u h^2}$

u = WIND SPEED, M/SEC

h = EFFECTIVE STACK HEIGHT, M

t_D = DECAY TIME, SEC = $t_v + \frac{1}{u}\left(\frac{h^2}{C^2}\right)^{\frac{1}{2-n}}$

t_v = DECAY TIME EN ROUTE TO STACK

C = ATMOSPHERIC DIFFUSION CONSTANT (SEE AECU-3066)

n = ATMOSPHERIC STABILITY PARAMETER (SEE AECU-3066)

Fig. 5

The downwind dose resulting from the release of gaseous fission products or aerosol through the vessel off-gas system is calculated from the relations given in Figs. 5 and 6. In calculating the effects of the gaseous fission products, it is assumed that a sustained or single burst of 10^{18} fissions occurs in the vessel and that the gaseous fission products continuously leave the vessel and are entrained as they are formed. For each gaseous radionuclide the maximum downwind dose is calculated by taking into consideration decay of the radionuclide in transit to the ground and the decontamination factor for the radionuclide in the vessel off-gas treatment system. In general, it may be assumed that the decontamination factor for xenon and krypton gases is 1 and that the iodine and bromine isotopes are decontaminated by a factor of 10-100 in the caustic scrubber. The aerosol release is calculated by assuming that aerosol is continuously generated in the vessel for a 1-hr period following the accident and is continuously entrained in the air which is normally flowing through the vessel off-gas manifold. It is assumed that the filter effluent contains a concentration of 0.14 mg per cubic meter of air which has the original solution composition of radioactive material.

The equations for evaluation of the cell ventilation system release are given in Fig. 7. It is assumed that a burst of 10^{18} fissions occurs which ruptures the process vessel and scatters its contents throughout the cell, terminating the reaction. It also assumes that the gaseous fission products are evenly distributed in the cell and remain mixed. The downwind dose is calculated by assuming that aerosol is entrained in a solume of air equivalent to one cell volume which passes through the exhaust at the bottom of the cell to the cell ventilation manifold. If one wished to take into account additional generation of aerosol which might occur in the cell ventilation manifold, one would multiply the aerosol downwind dose by the ratio of the air flow rate at the filter to the cell purge rate.

The effect of a release to the secondary containment shell may be calculated from the equations in Figs. 8 and 9. The volume of cell air which leaks to the secondary containment cell is calculated using the cell leak rate at 2 in. of water differential pressure and assuming turbulent flow during the period in which the cell is pressurized. An

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GROUND DOSE FROM VESSEL OFF-GAS SYSTEM RELEASE

A. GASEOUS FISSION PRODUCTS (FROM 10^{18} FISSIONS)

$$D_{AV} = \sum_i \left[\frac{Q_i^o \, e^{-\lambda_i t_D}}{X_i} \right] \frac{10^{-6} k}{(mpc)_i}$$

X_i = DECONTAMINATION FACTOR FOR i

λ_i = DECAY CONSTANT FOR i, SEC^{-1}

Q_i^o = CURIES OF i FORMED IN 10^{18} FISSIONS

$$= \frac{(10^{18} \lambda_i) \text{ (FISSION YIELD)}}{3.7 \times 10^{10}}$$

B. AEROSOL OF LONG-LIVED RADIOACTIVE SOLUTION

$$D_{BV} = \left[(A_V)(m)(0.14 \text{ mg}/M^3)(4.77 \times 10^{-4})(3.6 \times 10^3) \right] \frac{10^{-6} k}{(mpc)}$$

A_V = VOG FLOW RATE, cfm

m = CONC. OF ACTIVITY IN SOLUTION, CURIES/mg

Fig. 6

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GROUND DOSE FROM CELL VENTILATION RELEASE

A. GASEOUS FISSION PRODUCTS

$$D_{AC} = \sum_i \left[\frac{RQ_i^o \, e^{-\lambda_i t_D}}{(R + \lambda_i) X_i} \right] \frac{10^{-6} k}{(mpc)_i}$$

R = CELL AIR REMOVAL RATE CONSTANT= CELL VOLUMES/SEC

B. AEROSOL OF LONG-LIVED RADIOACTIVE SOLUTION

$$D_{BC} = \left[\frac{V_C \, (0.14) \, m}{35.3} \right] \frac{10^{-6} k}{(mpc)}$$

V_C = CELL VOLUME, cu ft

Fig. 7

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VOLUME OF RADIOACTIVE AIR RELEASED TO BUILDING
(SECONDARY CONTAINMENT SHELL)

V_L = LEAKAGE VOLUME, cu ft $= \frac{1}{W_L} \int_0^t P^{1/2}\, dt$

t = ELAPSED TIME WHILE CELL IS ABOVE ATMOSPHERIC PRESSURE

P = PRESSURE RELATIVE TO ATMOSPHERIC, in. H_2O

W_L = RESISTANCE, (in. $H_2O)^{1/2}$ / (cu ft/sec)

FOR A FACILITY IN WHICH ORNL CONTAINMENT CRITERIA ARE MET:

$$V_L \leq (0.1\ V_C) \frac{\left[\frac{V_{EX}}{V_C} - \frac{1}{407}\right] \left[\frac{407\ V_{EX}}{4\ V_C} - \frac{P_I}{4}\right]^{1/2}}{\left[\frac{407\ V_{EX}}{2\ V_C\ P_I} + 1\right]^{1/2}}$$

V_C = CELL VOLUME, cu ft

V_{EX} = EXPLOSION VOLUME, cu ft

Fig. 8

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PSEUDO TWO-MINUTE DOSE TO PERSONNEL BEFORE EVACUATION OF THE SECONDARY CONTAINMENT SHELL

A. GASEOUS FISSION PRODUCTS

$$D_{AP} = \sum_i Q_i^o \frac{V_L}{V_C} \left(\frac{1 - e^{-120\lambda_i}}{\lambda_i} \right) \frac{(35.3)\,(10^{-6})}{V_B\,(mpc)_i}$$

V_B = SECONDARY CONTAINMENT SHELL VOLUME, cu ft

B. AEROSOL OF LONG-LIVED RADIOACTIVE SOLUTION

$$D_{BP} = \left[(10\ mg/M^3)\,(m)\,(V_L) \right] \frac{(120)\,(10^{-6})}{V_B\,(mpc)}$$

Fig. 9

estimated dose to personnel in the secondary containment shell may be calculated by assuming that the leaked cell air is uniformly distributed in the volume of the secondary shell and personnel are exposed to this air for 2 min before evacuation. The concentration of aerosol in the leaked air is calculated by considering impingement which occurs in the tortuous path through the cell wall, and the gaseous fission product concentration is that concentration obtained by dispersing all the gaseous fission products in the volume of the cell.

The release of activity from the secondary containment shell is by two mechanisms: the normal ventilation flow through the absolute filter and the building leakage which occurs if there is a significant wind to create a lee vacuum on the building. The downwind ground concentration for individual gaseous fission products and the aerosol is calculated from the equations in Fig. 10. The downwind dose is the sum of the dose which occurs from the leak from the building during the 20-sec period required to evacuate the building to 0.3 in. w.g. vacuum and the release through the building ventilation system. For the gaseous fission products, appropriate corrections are made for decay inside the building and in transit through the building ventilation system.

6.1 Effect of Change in Cell or Building Tightness

A general equation for a 2-min dose to building personnel as a result of an aerosol release from a processing cell into the secondary containment is

$$D_s = \frac{2.0 \times 10^{-5}\ K_C m V_C}{V_B \times MPC} \left[\frac{101.5 V_E}{V_C} - \frac{P_I}{4}\right]^{1/2}$$

Rearranging terms into two parameters, one in terms of dose and activity and the other in terms of cell and building physical or structural properties, we get

$$\frac{D_s \times MPC}{m} = 2.0 \times 10^{-5}\ K_C \times \frac{V_C}{V_B} \left[\frac{101.5 V_E}{V_C} - \frac{P_I}{4}\right]^{1/2}$$

Thus a plot of

$$\frac{D_s \times MPC}{m} \quad \text{vs} \quad \frac{V_C}{V_B} \left[\frac{101.5 V_E}{V_C} - \frac{P_I}{4}\right]^{1/2}$$

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GROUND DOSE FROM SECONDARY CONTAINMENT SHELL RELEASE

A. GASEOUS FISSION PRODUCTS

$$D_{AS} = \sum_i Q_i^o \frac{V_L\ (10^{-6})}{V_C\ (mpc)_i} \left[\frac{R_L k_L \left(1 - e^{-(R_L + \lambda_i)20}\right)}{R_L + \lambda_i} + \frac{R_B k_B e^{-\lambda_i t_D}}{(R_B + \lambda_i)} \right]$$

R_L = LEAK RATE CONSTANT, SEC. CONT. VOLS/SEC = $\frac{6 \times 10^{-3}}{60}$

R_B = VENTILATION RATE CONSTANT, SEC. CONT. VOLS/SEC $\cong \frac{0.1}{60}$

k_L = ATMOSPHERIC DILUTION FACTOR FOR LEAK, SEC/M^3 (u = 30 mph)

k_B = ATMOSPHERIC DILUTION FACTOR FOR BUILDING VENTILATION, SEC/M^3

B. AEROSOL OF LONG-LIVED RADIOACTIVE SOLUTION

$$D_{BS} = \frac{(10)\ (m)\ (V_L)\ (10^{-6})}{(35.3)\ (mpc)} \left[k_L\ (1 - e^{-R_L t_L}) + k_B \left(\frac{C_F}{10}\right) \right]$$

C_F = PARTICULATE CONCENTRATION IN AIR LEAVING FILTERS $\approx$ 0.14 MG/M^3

t_L = TIME DURING WHICH BUILDING LEAKS (20 sec DESIGN BASIS)

Fig. 10

is a series of straight lines with K_C (cell leak constant, cell vol/min) as a parameter (Fig. 11).

Similarly, the general equation for the maximum downwind dose is

$$D_D = \frac{4.77\text{x}10^{-9}K_C m V_C}{MPC}\left[\frac{101.5V_E}{V_C} - \frac{P_I}{4}\right]^{1/2} \text{x} \left[k_L \text{ x } (1-e^{-K_B \frac{t}{60}}) + 1.4 \text{ x } 10^{-2}k_B\right]$$

if $K_B t/60$ is small then $(1 - e^{-\frac{K_B t}{60}}) \approx K_B \frac{t}{60}$, where K_B is the building leak constant in building vol/min and k_B = building ventilation system dilution factor, sec/m^3. Rearranging terms into two parameters as in the case for building personnel dose, we get

$$\frac{D_D \text{ x } MPC}{m} = 4.77\text{x}10^{-9}K_C V_C\left[\frac{101.5V_E}{V_C} - \frac{P_I}{4}\right]^{1/2} \text{x}\left[k_L \text{x}(1-e^{-K_B \frac{t}{60}}) + 1.4 \text{ x } 10^{-2}k_B\right]$$

Graphs were plotted of

$$\frac{D_D \text{ x } MPC}{m} \text{ vs } K_C V_C \left[\frac{101.5V_E}{V_C} - \frac{P_I}{4}\right]^{1/2}$$

with K_B as a parameter. A constant value of $1.7 \text{ x } 10^{-4}$ sec/m^3 was used for k_L (effective building leak dilution factor) with a time t of 20 sec for the cases in which the building ventilation system operates and 3600 sec for the cases in which the building ventilation system fails. A value of $1.6 \text{ x } 10^{-5}$ was used for k_B.

The downwind dose varies more with K_C than it does with K_B (Fig. 12). This is especially noticeable for the case where the building ventilation system fails. The variation of dose with K_C is directly proportional. This indicates that changes that can be made to tighten a cell are much more important than those used to tighten the building. A tight cell not only protects downwind facilities and personnel but also the operating personnel themselves. A tight building, however, serves both as a second line of defense (added safety factor) and also to help confine the major fraction of the activity as a result of a serious cell leak due to either a more severe explosion or an operational error.

6.2 Fallout of Radioactive Particulates

The second important hazard, i.e., in addition to the total internal or external dose received by operating personnel or personnel downwind of an accident could arise from deposition of radioactive particles. If

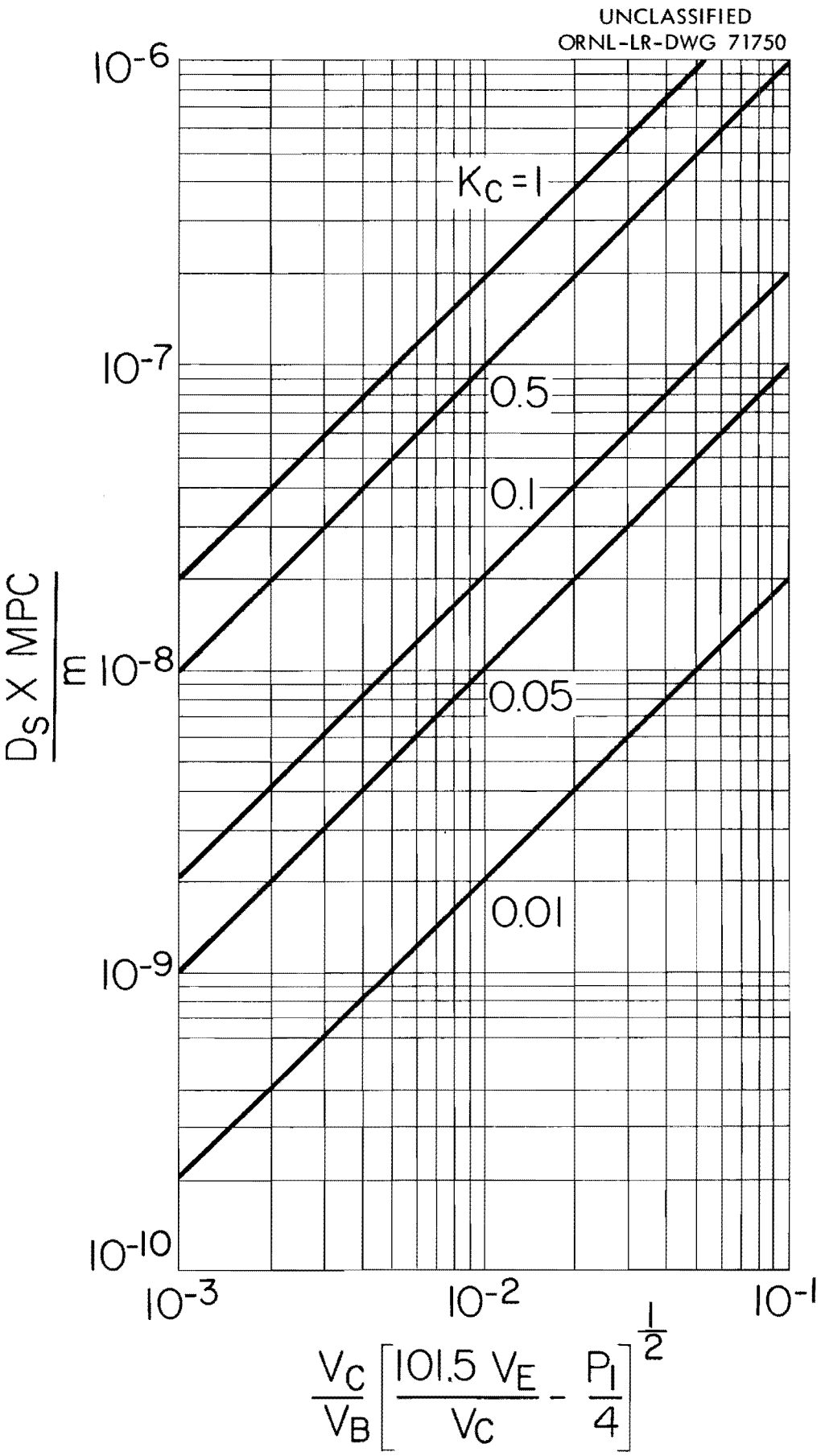

Fig. 11. Effect of cell leak constant on dose to building personnel.

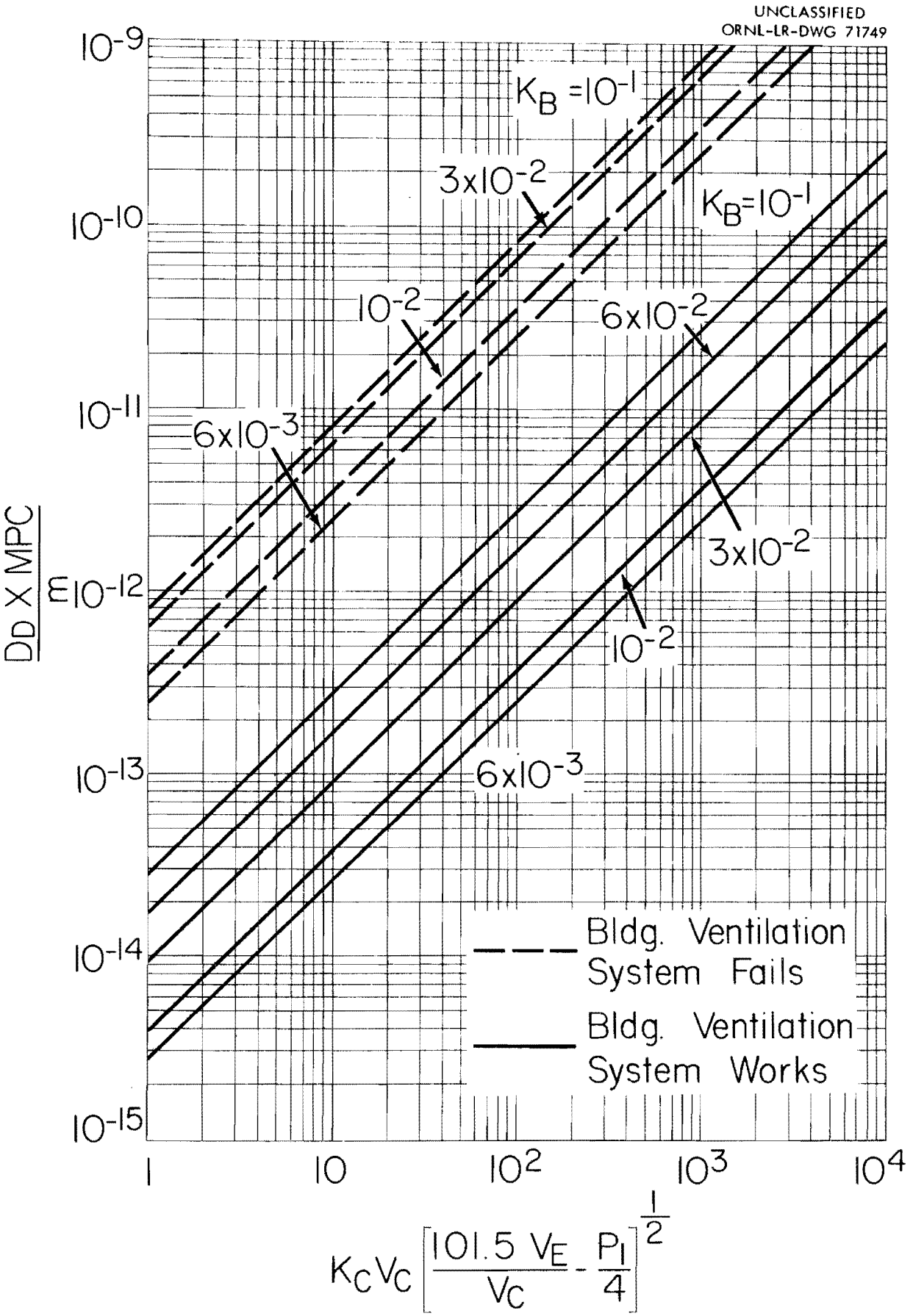

Fig. 12. Effect of building and cell leak constants on maximum downwind dose.

by deposition of air-borne particles the surrounding terrain becomes contaminated beyond permissible levels for alpha or beta-gamma activity, it may be necessary to decontaminate large areas surrounding the affected facility. Fallout is serious only for the fraction of the activity that escapes through a building leak, since any reasonable release from a tall stack will be diluted by many orders of magnitude before reaching ground level.

The hazardous level for beta-gamma contamination was considered to be that concentration in curies per square meter which would give a reading of 2.5 mr/hr above ground as determined by a Geiger-Mueller survey meter with an open window. For alpha materials the hazardous ground concentration in curies per square meter was considered to be the arithmetic product of 250,000 times the mpc_a for 40 hr exposure.

The deposition of particles results from the release of an aerosol after either a chemical or a nuclear explosion. The total deposition of particulate matter at any point x,y is given by the expression listed as Fig. 13.

7.0 RESULTS AND CONCLUSIONS

By the methods described we were able to show to our satisfaction that the effects of what we considered to be the maximum credible accident in ORNL radiochemical facilities, which have been revised to meet the containment criteria, result in acceptable personnel exposure and downwind ground contamination. In our large wet-chemical facilities, such as Bldg. 3019, it was calculated that operating personnel or Laboratory personnel downwind from the facility could receive no more than a few multiples of the weekly permissible dose and that the ground downwind from the facilities would not be contaminated beyond 10% of the maximum permissible ground level.

One significant conclusion has been that, even if the filter effluent concentration which we have assumed is conservative by a factor of 100, the controlling dose downwind from a facility is that due to the release through the filtered vessel and cell ventilation systems rather than from the release through controlled leaks in the cell and building. This suggests that the use of a filter with better particulate removal efficiencies than those which we assumed could conceivably justify the location

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GROUND CONTAMINATION FROM PARTICULATE RELEASE

$$\omega = \frac{2QV_g}{e\pi C_y C_z \bar{u} X^{2-n}} \; e^{-\left(\frac{Z_1^2 + Y^2}{C_y^2 X^{2-n}}\right)} \; e^{-\frac{4V_g X^{n/2}}{nu\pi^{1/2} C_z}}$$

$$\text{where} \quad Z_1 = h - \frac{XV_g}{\bar{u}}$$

Q = CURIES RELEASED

V_g = PARTICULATE SETTLING VELOCITY

C_y, C_z = DIFFUSION CONSTANTS

n = ATMOSPHERIC STABILITY CONSTANT

X, Y = DISTANCE DOWNWIND AND CROSSWIND, RESPECTIVELY

Fig. 13

of a secondarily contained radiochemical facility in an uncontrolled, populated area.

Table II illustrates the effects of filters and iodine absorbers on the dose received from activity released through the vessel and cell off-gas systems. The dose would increase by a factor of 70 if the absolute filter should be ruptured in an accident and that iodine-bromine absorption can decrease the effects of a criticality incident by a factor of 6.

Table III illustrates the effects of primary and secondary containment on dose and contamination to building personnel and surrounding terrain. If all containment criteria are met, there is no significant hazard. However, the hazard can be very serious if both the primary and secondary containment should have been breached either before or as a consequence of an accident. Good secondary containment will reduce the consequences of an accident even if the primary containment is breached. This figure also illustrates that a good primary containment is much more important than the secondary containment.

The results illustrated by these figures apply to a 1-tonne/day chemical processing plant for Yankee reactor fuel irradiated to 8400 Mwd/tonne.

It is our hope that these containment criteria and methods of evaluation will stimulate investigation, particularly into the properties of aerosols and efficiency of air cleanup devices. The availability of better hazards evaluation data and cleanup devices will permit more public assurance and more realistic containment and site location criteria for radiochemical plants. It will possibly also permit a more realistic assessment of the safety of industrial plants in which nonradioactive but physiologically hazardous chemicals are handled.

TABLE II

CELL AND VESSEL OFF-GAS HAZARDS

CONDITION	MAXIMUM DOSE (REM) FROM VOG SYSTEM	MAXIMUM DOSE (REM) FROM COG SYSTEM
WASTE EVAPORATOR		
FILTERS HOLD	7.5×10^{-4}	1.0×10^{-3}
FILTERS RUPTURE	5.4×10^{-2}	7.2×10^{-2}
Pu EXTRACTION SYSTEM		
AEROSOL		
FILTERS HOLD	9.8×10^{-4}	1.3×10^{-3}
FILTERS RUPTURE	7.0×10^{-2}	9.4×10^{-2}
CRITICALITY		
I_2 ABSORPTION	9.9×10^{-3}	4.0×10^{-2}
NO I_2 ABSORPTION	5.5×10^{-2}	

TABLE III

HAZARDS TO BUILDING AND SURROUNDINGS

WASTE EVAPORATOR - YANKEE FUEL PLANT

	CONTAINMENT CRITERIA	NO SECONDARY CONTAINMENT	PRIMARY AND SECONDARY CONTAINMENT BREACHED	PRIMARY CONTAINMENT BREACHED GOOD SECONDARY CONTAINMENT
MAX. DOSE TO BUILDING PERSONNEL (REM)	3.5×10^{-2}	---	63	63
MAX. DOWNWIND DOSE (REM)	1.4×10^{-6}	4.2×10^{-4}	0.76	2.5×10^{-3}
FALLOUT AT 10 m (c/m^2)	8.0×10^{-9}	4.0×10^{-6}	7.3×10^{-3}	1.5×10^{-5}
(FACTOR x HAZARD LEVEL)	3.8×10^{-5}	1.9×10^{-2}	35	7×10^{-2}
DISTANCE AT WHICH GROUND NEEDS DECONTAMINATION (m)	0	0	275	< 10

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