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ENVIRONMENTAL EXPOSURE AS A
FUNCTION OF CONTAINMENT VESSEL LEAKAGE RATE¹

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INTRODUCTION

Reactor containment buildings for protection of the public have been designed for very low leakage rates. Considerable effort has been expended on the maintenance and testing of these vessels to insure that the initial low leakage rate has not deteriorated. It generally has not been the practice to determine the required quality of the reactor container for a given site, particularly with regard to varying leakage rates. Extra expense has been accepted as necessary because of the tendency to always provide containment vessels which are as leak-tight as possible.

Recent meteorological studies at Hanford have led to the development of more refined mathematical models for estimating the atmospheric dispersion of gaseous and air-borne contamination.

In this study these new calculational models have been applied to a particular reactor, the Plutonium Recycle Test Reactor (PRTR), comparing various containment conditions. The Operating Safety Limits prescribed

by the Commission for PRTR establish a maximum allowable leakage rate of one percent of the contained vapor per day for the containment vessel. For illustrative purposes, however, other containment possibilities were assumed with the result of different leakage rates and paths existing in the unlikely event of a reactor accident. This paper presents a study of the effect of these leakage rates upon environmental exposure.

THE REACTOR

The PRTR is a vertical pressure tube type reactor, heavy water moderated and cooled. A vertical section through the reactor is shown in Figure 1. Fuel elements are charged into and discharged from the 85 Zircaloy-2 pressure tubes from the top face.¹

Control of the reactor is achieved by regulating the level of the low temperature, 150 F, unpressurized, heavy water moderator, which is held in the reactor vessel by a helium gas balance system. Fifty-four shim rods are provided, in 18 locations, to compensate for local flux perturbations and to permit adjustment of the moderator level to the desired control range for equilibrium operation. Emergency shutdown (scram) is achieved by a gas-balance moderator dump system which drains the moderator from the calandria at a rate in excess of 20,000 gpm.

FIGURE 1

Reactor Core and Shielding

The primary coolant system operates at a nominal pressure of 1050 psig. Heavy water coolant is circulated through pressure tubes removing the heat generated in the fuel elements and increasing in average temperature from 440 to 520 F. Heat is removed from the primary coolant by vaporizing light water in a heat exchanger to generate 200 psia steam. Some of the steam is used to supply the need of the adjacent 300 Area and the rest is condensed in a barometric condenser before disposal to the Columbia River.

A cylindrical steel containment vessel, 80 feet in diameter and 121.5 feet in height, houses all of the process area except the storage basin and an underground annex which houses process equipment of the Fuel Element Rupture Test Facility. The design pressure of the containment vessel is 15 psig. The reactor is located on the building centerline below the reactor hall floor, which is at grade. The arrangement is shown in Figure 2. Ventilation ducts and piping larger than one-fourth inch pipe size penetrating the containment shell are equipped with containment valves. During normal operation, ventilation air progresses towards areas of higher potential contamination, and is discharged through high efficiency particulate and charcoal filters to the atmosphere from a 150-foot high stack. The containment vessel is maintained at a slightly negative pressure during reactor operation. Normal access is through a personnel air lock and a small air lock is provided for emergency use. Large equipment pieces may be moved through a freight door which may be opened only when the reactor is shut down.

FIGURE 2

Plutonium Recycle Test Reactor and Building

The PRTR is located close to the Columbia River, near the southern boundary of the Hanford Reservation. Richland, Washington, the nearest city, is about four miles south of the reactor. Location of the Hanford Reservation with respect to the major population centers in the Pacific Northwest is shown in Figure 3. Features in the vicinity of the PRTR are shown in Figure 4.

The maximum credible accident in the PRTR has been described as the rupture of the top 14-inch primary coolant header accompanied by the simultaneous loss of backup coolant.¹ Loss of the primary coolant has a negative effect on reactivity of the reactor; therefore, this accident would not initiate a nuclear excursion. Drastic changes in the primary system pressure and pressure tube flow rates would automatically trip the safety circuit and shut down the reactor. Heating of the uncooled fuel elements by fission product decay would eventually lead to fuel element melting and the release of fission products to the reactor building.

Blowdown of the primary coolant through an 0.80 sq ft rupture in the top 14-inch line has been calculated to have an initial discharge rate of 5000 lb/sec decreasing rapidly to 1150 lb/sec in 0.5 second.² The discharge rate would continue to decrease slowly to 400 lb/sec at 26.5 seconds when the blowdown would be virtually complete. Steam would continue to flow from the rupture until 42 seconds after the incident when the primary coolant system pressure would have decayed to 24 psia.

FIGURE 3

Geographical Relationship
of Hanford Works to Pacific Northwest

FIGURE 4

Features of Hanford Project and Vicinity

Fuel element melting would be expected to start about 3 to 4 minutes after the incident and continue for about 90 minutes. Molten zirconium from the fuel element jackets and the pressure tubes would react with water contributing about 2,600,000 Btu of chemical energy.

Two basic containment concepts were assumed for the operation of the PRTR containment vessel in this study, pressure containment and confinement. The first concept assumed was that under which the PRTR is authorized to operate, i.e., all ventilation and aqueous containment valves are closed immediately following loss of coolant. The other concept of operation assumed that the PRTR containment vessel was provided with an additional pressure relief system. It was assumed that in this system the pressure buildup in the building from blowdown of the primary coolant system was held to a relatively low level by relieving the building pressure to the stack through a bypass line around the exhaust air filters and collectors. Following pressure relief the by-pass line would be closed and any pressure buildup would be relieved through the filter system and the 150 feet high stack. Throughout the remainder of this report, the first method of operation shall be referred to as containment and the latter method as confinement. Both operating concepts are evaluated with and without the existing water fog spray system. It must be clearly understood that a confinement method of operation of the PRTR has not been proposed and certainly is not authorized. It is strictly a hypothetical case used in this study to illustrate its possible effects upon environmental exposure in the unlikely event of a major accident.

Case I - Containment with Water Fog Spray

The estimate of the conditions existing in the containment vessel for this case were made in accordance with the design of the PRTR containment system, using the installed water fog spray system to reduce the containment vessel pressure after the coolant blowdown. It was assumed that the water fog spray was started five minutes after the incident. The containment building pressure transient for this case is shown in Figure 5. The maximum building pressure of the transient, about 9.5 psig, would be reached in about five minutes when it is assumed that the water fog spray is turned on. Building pressure would return to atmospheric about one-half hour after the pipe rupture. At the peak pressure the leakage rate from the containment vessel would be about 0.8 per cent per day, assuming that the leakage rate varies as the square root of the pressure.

Case II - Containment without Water Fog Spray

In this case it was assumed that the water fog spray did not function. The mechanical refrigeration system installed for normal temperature control in the containment building has a capacity of 1.2 million Btu per hour. It was assumed that this heat removal capacity would be available following the incident. The calculated pressure transient for this situation is shown in Figure 6. Pressures greater than atmospheric would be expected to persist for about two days and the peak pressure of 19 psig would be expected to occur

BNSA-9

Containment Vessel Pressure - psig.

FIGURE 5

Case I. Containment Vessel Pressure
Transient with Water Fog Spray

Time - seconds

BNSA-9

Containment Vessel Pressure - psig.

FIGURE 6

Case II. Containment Vessel Pressure
Transient without Water Fog Spray

Time - seconds

8 hours after the pipe rupture. The containment vessel pressure would exceed 15 psig for about one-third of this time.

Case III - Confinement with Water Fog Spray

It was assumed that the PRTR was provided with a filter bypass pressure relief system, which maintains the containment vessel pressure at or near atmospheric pressure. Five minutes after the start of primary coolant blowdown automatic valve operation would route the exhaust vapor through the filter, a high efficiency particulate filter followed by a charcoal filter. In this case it was further assumed that the water fog spray would be turned on five minutes after the incident. Cooling of the confined vapor by the spray would reduce the flow rate from the building to about 200 cfm. This low flow purge rate was assumed to be maintained indefinitely following the accident. The initial flow rate transient from the building is shown on Figure 7.

Case IV - Confinement without Water Fog Spray

Conditions of flow from the building and pressure in the building would be the same as in Case III until five minutes after the pipe rupture. Since there would be no water fog spray in this case, the flow rate from the building after five minutes would be greater than in Case III. As shown in Figure 7, the flow rate from the building through the filters would be stabilized at 2400 cfm.

FIGURE 7

Cases III and IV. Exhaust Flow Transient
During Confinement

FISSION PRODUCT RELEASE

Following loss of coolant, fission products, normally contained by the zirconium cladding of fuel elements, would have to travel a tortuous path before they could be released to the atmosphere. This path has been categorized into several major components, viz: (a) release from molten fuel; (b) travel from location of fuel cladding failure to location of leakage, and, in the case of confinement; (c) passage through the absorber and filter. The quantity of fission products passing through each of these components depends upon both their physical and chemical characteristics. For this study, it is assumed that released fission products which are not in a gaseous state, are present in particulate form of very small diameter (< 20 microns). For convenience, fission products are grouped as:

Noble Gases (NG)	krypton, xenon
Halogens (H)	bromine, iodine
Volatile Solids (VS)	selenium, tellurium, cesium
All Remaining Fission Products (ARFP)	

The assumed release of fission product groups at each stage is listed in Table I.

TABLE I
FISSION PRODUCT RELEASE

	<u>Fraction of Fission Product Group</u>			
	<u>NG</u>	<u>H</u>	<u>VS</u>	<u>ARFP</u>
Fission Product Inventory in Failed Fuel Escaping:				
1. Fuel	1.0	0.5	0.5	0.01
2. Plate-Out	1.0	0.5	0.3	0.3
3. Wash-Out	1.0	0.5	0.5	0.5
4. Filter or Collector	1.0	0.05	0.0005	0.0005

The inventory of radioactive fission products contained in the core of the PRTR has been computed by a Hanford developed FORTRAN program. Table II summarizes the core inventory for assuming 120 Mw(th) operation. (Note: PRTR is currently limited to 70 Mw(th) operation.) Following total loss of coolant it is assumed that the portion of the core containing 50% of the radioactive inventory would melt.

The containment vessel leakage rate of fission products for each of the previously discussed cases is based on; (1) the volume of free air space in the PRTR containment vessel, e.g. approximately 400,000 cubic feet, (2) the volumetric leakage rate corresponding to Figures 5, 6 and 7, (3) the fractional escape values listed in Table I

TABLE II

QUANTITIES OF RADIONUCLIDES IN THE PRTR
(curies)

	Power Level (Mw)	Shutdown	Decay Time						
			5 min	10 min	1 hour	10 hours	1 day	10 days	100 days
Noble Gases	120	5.9 (7	2.4 (7	2.0 (7	1.4 (7	1.0 (7	8.4 (6	2.2 (6	1.6 (4
Halogens	120	5.0 (7	3.0 (7	2.9 (7	2.6 (7	1.5 (7	1.0 (7	2.1 (6	6.5 (2
Volatile Solids	120	6.6 (7	3.3 (7	3.0 (7	1.7 (7	7.3 (6	6.6 (6	2.3 (6	4.4 (5
All Remaining Fission Products	120	4.3 (7	3.1 (8	2.8 (8	2.2 (8	1.8 (8	1.6 (8	1.1 (8	2.7 (7
Total Fission Products	120	<u>6.1 (7</u>	<u>3.9 (8</u>	<u>3.6 (8</u>	<u>2.8 (8</u>	<u>2.1 (8</u>	<u>1.8 (8</u>	<u>1.1 (8</u>	<u>2.7 (7</u>

Note: 5.9 (7 is 5.9×10^7

and (4) the inventory of radioactive fission products in the failed fuel. The resulting leakage rate for each of the cases are summarized in Table III.

DOSE CALCULATION

The dose rate to the total body (d_{TB}) at ground level resulting from being immersed in an air-borne cloud of radioactive materials:

$$d_{TB} = 0.26 c_a \hat{E}_\gamma \quad (1)$$

where:

d_{TB} = dose rate (rad/sec)

c_a = air concentration in $\mu\text{c/cc}$

$\hat{E}_\gamma$ = energy of the gamma radiation in Mev/disintegration

The air concentration (c_a) in a plume resulting from the continuous discharge of contaminants to the atmosphere is:

$$c_a = \Lambda Q \left(\frac{E}{Q_a} \right) \quad (2)$$

where:

c_a = air concentration, $\mu\text{c/cc}$

Λ = leak rate constant, per unit time

Q = quantity emitted - curies

Q_a = quantity emitted and still airborne at the point of interest - curies

E = time-integrated air concentration at ground level from a point source of emission - $\mu\text{c-sec per cc}$

TABLE III

INITIAL RADIOACTIVE LEAKAGE RATES
(AT FIVE MINUTES AFTER SHUTDOWN)

<u>Containment Vessel Operation</u>	<u>Fractional Release Rate (min⁻¹)</u>	<u>Release Rate for Each Fission Product Category (in curies per minute at five minutes)</u>			
		<u>Noble Gases</u>	<u>Halogens</u>	<u>Volatile Solids</u>	<u>All Remaining Fission Products</u>
Case I	7 (-6	8.4 (1	1.3 (1	8.6 (0	1.6 (0
Case II	7 (-6	8.4 (1	2.6 (1	1.7 (1	3.3 (0
Case III	6 (-4	7.2 (3	5.4 (1	3.7 (-1	7.0 (-2
Case IV	6 (-3	7.2 (4	1.1 (3	7.4 (0	1.4 (0

Note: 7 (-6 is 7×10^{-6} .

Diffusion models have been employed at Hanford to estimate the consequences of releases of short duration. The geometry of the plume of air-borne material discharged from a point source is expressed as a bivariate normal distribution:

$$E = \frac{Q_a}{\pi \sigma_y \sigma_z \bar{u}_h} \exp \left[-\frac{1}{2} \left(\frac{y^2}{\sigma_y^2} + \frac{h^2}{\sigma_z^2} \right) \right] \quad (3)$$

where:

$\bar{u}_h$ = average wind speed at height of emission - meters per sec

y = horizontal distance from plume axis - meters

h = height of release - meters

σ_y^2 and σ_z^2 = horizontal and vertical cross wind variances
meters²

Values of the parameters σ_y^2 and σ_z^2 have been calculated from diffusion experiments conducted at Hanford over a wide range of atmospheric conditions.³

As the cloud moves downwind, it is depleted by ground deposition. The fraction of material still air-borne at any downwind distance is:

$$\frac{Q_a}{Q} = \exp \left[-\sqrt{\frac{2}{\pi}} \left(\frac{V_A}{\bar{u}_0} \right) \left(\frac{\bar{u}_0}{\bar{u}_h} \right) \int_0^x \frac{\exp (-h^2/2\sigma_z^2)}{\sigma_z} dx \right] \quad (4)$$

where:

V_{Δ} = deposition velocity - meters per second

$\bar{u}_0$ = average wind speed at ground level - meters per second

x = downwind distance - meters

The quantity of radioactive material emitted at the source is, of course, under going radioactive decay. For a mixture of radionuclides the decay can be expressed as:

$$Q = \sum_i q_i^0 e^{-\lambda_i t} \quad (5)$$

where:

q_i^0 = quantity of the i^{th} radionuclide present at the time of shutdown - curies

λ_i = radioactive decay constant of the i^{th} radionuclide - per unit time

t = time after shutdown in units of time consistent with λ_i

For a mixture, the effective energy, $\hat{E}_Y$ is also a function of decay time and can be expressed as:

$$\hat{E}_Y = \sum (\bar{E}_Y)_i q_i^0 e^{-\lambda_i t} \quad (6)$$

where:

$$(\bar{E}_\gamma)_i = \text{effective } \gamma\text{-energy of } i^{\text{th}} \text{ radionuclide}$$

When the cloud dimensions are not large with respect to the relaxation length of the gamma radiation, calculations based on semi-infinite clouds with a concentration equal to the ground level concentration at the point in question are subject to error. Graphic presentation of detailed calculations based on quadruple integration in space and time allow for this finite geometry. Calculations for cases where the cross wind dilution and the vertical dilution are equal, $\sigma_y = \sigma_z$, have been reported by Waterfield and Gamertsfelder.⁴ When $\sigma_y = \sigma_z$, as in the present case, some modification is required. Except for an elevated release, this modification has not yet been made.

In the present study, the height of emission is assumed to be 50 meters. For stable atmospheres and wind speeds of at least one meter per second, the infinite cloud assumption is valid at distances greater than 2000 meters. This is the approximate distance to the peak air concentration at ground level. Solutions for cloud size corrections for an elevated release have been compared with the infinite cloud assumption. It was our conclusion that, for close-in distances, substituting the maximum value of Equation (3) resulted in a close approximation to the several rigorous and complex finite cloud size equations.

Such an approximation is valid to within 20 percent for distances as close as 100 meters.

A recent analysis of Hanford meteorological data³ shows that wind variability during prolonged emissions results generally in greater dispersion and hence lower estimates of the time integrated air concentration. For this analysis, it has been assumed that the postulated release occurs during the winter months. It is further assumed that the initial release coincides with the beginning of a prolonged period of stability. Thus, the initial release is assumed to take place during a time of minimum dilution.

The release rate is not constant due to radioactive decay and to source dilution. It is necessary, therefore, to account for the change in release rate during the several time intervals in which wind variability have been measured. The release rate is assumed to vary as:

$$\Lambda Q = (\Lambda Q)_0 \exp [-\Lambda(t - t_m)] \quad (7)$$

where:

Q is defined by Equation (5)

Λ = volumetric leakage rate constant - per unit time
see Table III

$(\Lambda Q)_0$ = initial leakage rate as given in Table III

t_m = time after shutdown at which the release begins

By substitution, Equation (1) can now be expressed as:

$$d_{TB} = 0.26 \hat{E}_Y \Lambda Q \left(\frac{Q_a}{Q} \right) \left(\frac{E}{Q_a} \right) \quad (8)$$

ΛQ is defined by Equation (7)

$\hat{E}_Y$ is defined by Equation (6)

where:

Q is defined by Equation (5)

$\left(\frac{Q_a}{Q} \right)$ is defined by Equation (4)

$\left(\frac{E}{Q_a} \right)$ is defined by Equation (3)

The dose to total body is;

$$D_{TB} = \int_T^{T+\tau} d_{TB} dt' \quad (9)$$

where the lower limits of integration is the time of transport, T to the point of interest and the upper limit is the additional time τ of exposure. It is not possible to integrate Equation (9) analytically, therefore it has been numerically integrated.

Referring to Table II and Equation (8), the dose rate during the j^{th} time interval from any fission product group is;

$$(d_{TB})_j = 0.26 \hat{E}_Y \Lambda Q \left(\frac{E}{Q} \right)_j \quad (10)$$

where Q now is the quantity in any one of the several fission product categories listed in Table II. During the j^{th} time interval, it is assumed that the normalized time-integrated air concentration is constant with respect to the time of emission. It is further assumed that at any downwind distance, the exposure time, τ , at that distance is of the same duration as the emission. Thus, the dose from a fission product group, during the j^{th} time interval, at a point T minutes downwind is:

$$(D_{\text{TB}})_j = 0.26 \left(\frac{E}{Q} \right)_j \int_T^{T+\tau} \hat{E}_Y (\Delta Q) dt \quad (11)$$

and the dose after several time intervals is:

$$D_{\text{TB}} = \sum_j (D_{\text{TB}})_j \quad (12)$$

Total body dose from penetrating radiation as defined by Equation (12), has been evaluated for each fission product category and for each of the four cases previously described. The effect of wind variability was evaluated using Hanford meteorological data. The resulting evaluations are discussed for each of the cases studied.

Case I. This case assumes that the containment system including the fog spray system, functions as intended. It assumed conservatively that the leakage of fission products from the containment

begins at five minutes after shutdown and continues at a constant rate for one hour. It is assumed that the release is at ground level and all but filter correction factors listed in Table III apply. Table IV lists the total body dose, from penetrating radiation, at a point on the center line of the cloud for three arbitrarily selected transport times. These times correspond to 600, 1500, and 4200 meters.

Case II. This case assumes that the fog spray does not work and as a result the leakage continues for a period greater than eight hours. The leakage rate is assumed to be the same as in Case I. The release height is at ground level and all the correction factors, except for filtration and for fog spray, of Table III have been applied. The total body doses from each of fission product groups are plotted in Figures 8 and 9. The curves are for a point 600 meters downwind and on the centerline of the cloud. Figure 8 is for an invariant wind and Figure 9 assumes wind variability.

Case III. This case is an elevated release case which assumes fog spray operation followed by a relatively slow leakage rate (e.g. 240 cfm) through the filter and collector system. It is assumed that the release height is 50 meters and that all of the correction factors of Table III apply. The major contributor to the total body dose in this case is due to the noble gases (~ 98%) with halogens contributing about 2 percent. The dose at 2400 meters, from

TABLE IV

TOTAL BODY DOSE - CASE I

<u>Transport Time (minutes)</u>	<u>Fission Product Group</u>	<u>Total Body Dose (rems)</u>	
		<u>Variable Wind</u>	<u>Invariant Wind</u>
10	Noble Gases	0.74	1.2
	Halogens	0.17	0.28
	Volatile Solids	0.060	0.098
	All Remaining Fission Products	0.008	0.013
	All	0.98	1.6
25	Noble Gases	0.20	0.31
	Halogens	0.044	0.071
	Volatile Solids	0.016	0.026
	All Remaining Fission Products	0.002	0.004
	All	0.26	0.41
70	Noble Gases	0.035	0.054
	Halogens	0.0078	0.012
	Volatile Solids	0.0033	0.0051
	All Remaining Fission Products	0.0005	0.0008
	All	0.047	0.047

FIGURE 8
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS
CASE II Distance 600 meters
Invariant Wind

FIGURE 9
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS
CASE II Distance 600 meters
Variable Wind

an unfiltered release for an invariant wind is plotted in Figure 10. Figure 11 is a similar plot but for a variable wind. Values for a filtered release are essentially those due to the noble gases.

Case IV. This case differs from Case III in that it is assumed that the fog spray system fails to function. As a result, the leakage rate is increased (e.g. 2400 cfm) and the correction factor for fog spray is omitted. As before the doses from the unfiltered release are plotted because of predominance of the noble gases when the release is filtered. Total body dose at 2400 meters, from an unfiltered release with an invariant wind is shown in Figure 12. Figure 13 is a similar plot but includes wind variability. As in Case III, the dose from a filtered release would be closely approximated by the curves for noble gases plus daughters.

The total body dose from fission products released are plotted for arbitrarily selected transport times in Figures 14, 15 and 16. The dose for both with and without wind variability are shown.

A comparison of the doses, after eight hours of exposure at 4200 meters, is made in Table V.

The effect of wind variability upon dose calculations is readily apparent from Table V. Depending upon the rate of release, the total body dose with wind variability is reduced to about one-third of that calculated on the basis of invariant wind. This factor

FIGURE 10
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS

CASE II WITHOUT FILTERS

Distance 2400 meters

Invariant Wind

All Fission Products

Noble Gases (plus daughters)

Halogens (plus daughters)

Volatile Solids (plus daughters)

ARFP (plus daughters)

TOTAL BODY DOSE - REMS

EXPOSURE TIME - HRS

BNSA-9

FIGURE II
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS
CASE III WITHOUT FILTERS

Distance 2400 meters
Variable Wind

FIGURE 13
TOTAL BODY DOSE
 From
RELEASED FISSION PRODUCTS
CASE IV - WITHOUT FILTERS
 Distance 2400 meters
 Variable Wind

46 6010
 KEUFE & ESSER CO.
 KEUFE & ESSER CO.
 46 6010
 KEUFE & ESSER CO.
 46 6010
 KEUFE & ESSER CO.

FIGURE 19
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS
CASE II

--- Invariant Wind
— Variable Wind
+ 1 hour Release
(Case I)

TOTAL BODY DOSE - REMS

KE SEMI-LOGARITHMIC 46 6010
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURE 15
TOTAL BODY DOSE
from
RELEASED FISSION PRODUCTS
CASE III

--- Invariant Wind
— Variable Wind

FIGURE 16
TOTAL BODY DOSE
FROM
RELEASED FISSION PRODUCTS
CASE IV

--- Invariant Wind
— Variable Wind

TABLE V

COMPARISON OF TOTAL BODY DOSES
FOR CASES II, III AND IV AFTER
EIGHT HOURS EXPOSURE AT 4200 METERS

<u>CASE</u>	<u>TOTAL BODY DOSE - REMS</u>	
	<u>Invariant Wind</u>	<u>Variable Wind</u>
I	0.073*	0.047*
II	0.40	0.12
III (filtered release)	7.1	2.3
IV (filtered release)	37	16

* exposure time - 1 hour.

does not hold for Case I because of the relatively short duration of release. This preliminary study is encouraging. Further refinements are being made to the mathematical model. These include modifications which will enable handling the finite size of the cloud at close-in distances and extended line and volumetric sources.

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