Air Activation from End Station C operation with continuous ventilation and no He bag

Bob May and Geoff Stapleton

Radiation Control Group Note 95-1

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- R. May
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Introduction

The derivation of the design release rates and consequent dose to the critically exposed off-site individual member of the population was based on optimal operating conditions, viz., no release during beam on and release only when beam is off. The result of this calculation gave total annual releases of 12 mCi/y and 5 10^{-5} mrem/y to the critical individual in the general population.

Hall C may be considered a confined space for access purposes after some period of operation - venting and verification of suitability of the air for occupation would be required before any access. To avoids these problems, currently hall is continuously purged by a 1000 cfm fresh air input .

The release of radioactivity continuously during beam on periods without the helium bag downstream of the target chamber will drastically increase release rates but the overall dose rates to the critical individual does not necessarily scale in proportion to the increase in release rate. We will show this by performing an actual analysis using the dispersion code CAP88. In addition some other calculations will be done to show the on-site effects of high release rates of short lived, immersion type radionuclides.

Production and Decay of Activated Air

The continuous production and release of activated air can be simply derived:

$$\frac{dN}{dt} = P - \lambda_{dec} N - \lambda_{vent} N$$

where P is rate of production of radionuclides

λ_{decay} radioactive decay constant (time^{-1})

λ_{vent} ventilation constant (R/V)

Let

$$\lambda_{eff} = \lambda_{decay} + \lambda_{vent}$$

then

$$P = \frac{N\lambda_{eff}}{1 - e^{-\lambda_{eff} t}}$$

Thus at any time, t, the number of atoms present N(t) will be given by:

$$N(t) = P\frac{\left(1 - e^{-\lambda_{eff} t}\right)}{\lambda_{eff}}$$

and the radioactivity:

$$A(t) = N(t)\lambda_{dec} = P\frac{\left(1 - e^{-\lambda_{eff} t}\right)\lambda_{dec}}{\lambda_{eff}}$$

Therefore when t is very long the activity is given by:

$$A(\infty) = P\frac{\lambda_{dec}}{\lambda_{eff}}$$

In the above equation P becomes the saturation activity and A(∞) the "reduced" saturation activity.

Table 1. below is reproduced from TN-94-031 April 8, 1994 (Table 2) and gives the saturation activities for the photo production of the relevant air activation radionuclides. For the full electron beam entering the air they are likely to be low, possible by a factor 5.

Table 1 Estimated Yields of Radionuclides from Photoactivated Air (Swanson's published figures given in the last column)

radio nuclide	parent elem	parent at wt	wt fract parent	reactn	sig-2 mb/MeV	equn 6 Bq/kW.m	nucl tot Bq/kW.m	Swa 79 Bq/kW.m
H - 3	N	14	7.55E-01	(g, T)	0.002	5.6E+06	7.1E+06	5.0E+06
	O	16	2.30E-01	(g, T)	0.002	1.5E+06		
Be - 7	N	14	7.55E-01	(g, sp)	0.0003	8.4E+05	1.1E+06	1.0E+06
	O	16	2.30E-01	(g, sp)	0.0003	2.2E+05		
C - 11	C	12	1.24E-04	(g, n)	0.073	3.9E+04	1.1E+07	1.0E+07
	N	14	7.55E-01	(g, T)	0.003	8.4E+06		
	O	16	2.30E-01	(g, an)	0.003	2.2E+06		
N - 13	N	14	7.55E-01	(g, n)	0.04	1.1E+08	1.1E+08	1.0E+08
O - 15	O	16	2.30E-01	(g, n)	0.075	5.6E+07	5.6E+07	5.6E+07
Cl - 38	Ar	40	1.30E-02	(g,np)	0.04	6.8E+05	6.8E+05	2.2E+05
Cl - 39	Ar	40	1.30E-02	(g, p)	0.5	8.5E+06	8.5E+06	1.5E+06

Using the data in column 8 of table 1 and the following data:

air removal rate R	1000 cfm (28 m^3 min^{-1}) for hall C
volume of hall C	2.7 10^4 m^3
hence λ_{vent}	10^{-3} min^{-1}
beam power	16 kW (1.6 GeV @ 10 μA)
length of beam path	25 m of air (no He bag)

we obtain the reduced saturation levels set out in table 2.

Table 2. Approximate Release Rates for the Relevant Radio nuclides

radio nuclide	lamda dec 1/min	lamda vent 1/min	nucl tot prod'n Bq/kW.m	reduced sat Bq	av conc in hall Bq/m3 (sat)	act rel'ed per day Ci (sat)	act rel'ed per day Ci (1day radn)	act rel'ed per day Ci (5 day radn)
H - 3	1.07E-07	1.00E-03	7.10E+06	3.04E+05	1.13E+01	1.23E-05	1.00E-09	1.31E-09
Be - 7	8.90E-06	1.00E-03	1.10E+06	3.88E+06	1.44E+02	1.57E-04	1.06E-06	1.38E-06
C - 11	0.0338	1.00E-03	1.10E+07	4.27E+09	1.58E+05	1.72E-01	1.68E-01	1.68E-01
N - 13	0.0693	1.00E-03	1.10E+08	4.34E+10	1.61E+06	1.75E+00	1.73E+00	1.73E+00
O - 15	0.33	1.00E-03	5.60E+07	2.23E+10	8.27E+05	9.01E-01	8.99E-01	8.99E-01
Cl - 38	0.0187	1.00E-03	6.80E+05	2.58E+08	9.56E+03	1.04E-02	9.89E-03	9.89E-03
Cl - 39	0.0126	1.00E-03	8.50E+06	3.15E+09	1.17E+05	1.27E-01	1.18E-01	1.18E-01

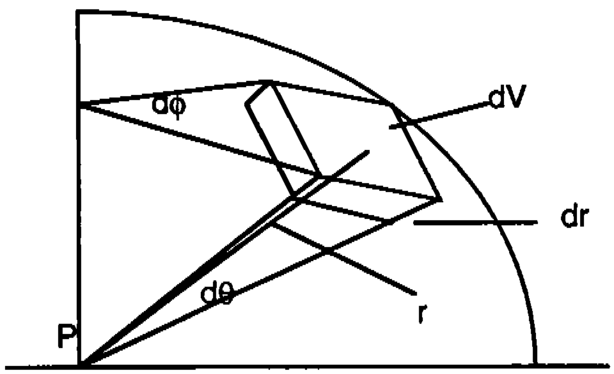
We note that for saturation values i.e., long irradiation times the release rates for the long half life radionuclides is much larger (column 7) than for the short irradiation times (columns 8 & 9). However, the short half life radionuclides C-11, N-13 and O-15 are seen to be close to saturation after a very short irradiation period.

Dose Rates to People Immersed in a Cloud of Activated Air

Let us consider the dose rates and radiological controls for people who enter the hall immediately after shut-down and anyone standing in the exhaust plume.

On the basis of the current regulation, for posting and controlling exposure to airborne radioactivity, we are not allowed to take credit from immersion exposure in anything other than a semi infinite cloud. Because of the decay of short half life radionuclides during plume or cloud development or confinement in a limited volume, it is impossible to achieve an infinite cloud[1]. Thus taking a one day irradiation time we note that the occupational exposure must be taken as about 15 DAC's (derived air concentrations). One DAC in a semi infinite cloud would result in a external dose rate of 2.5 mrem/hr. In 2000 hours this results in 5 rem, the legal limit for occupational exposure. The requirement for posting an Airborne Radiation Area is 0.1 DAC. As a result there would be a delay of approximately 1 hour before the activity would decay to 0.1 DAC (which is currently the approximate activity in the hall air after shutdown). In addition, any movement of the hall air into personnel access ways or other halls would necessitate careful evaluation of the airborne activity levels in those locations during beam on conditions. Additional controls in those areas may also be necessary.

A realistic model for calculating the likely dose rates assumes a large hemispherical bubble of air over the person in the hall. We now calculate the maximum dose rate to a person standing in the middle of the hemispherical bubble on the assumption there is perfect mixing. From the figure below:



Let

S = activity per unit volume
SdV = activity in vol element dV
K= k factor (dose rate rem/h at 1 m per curie)

dose at P due to SdV is given by:

$$\frac{KSdV}{r^2}e^{-\mu r}$$

where μ is some photon attenuation coefficient in air,

[1]Here we have an example of regulation requiring us to do a physically inappropriate calculation.

Now

$$dV = rd\theta . r\cos\theta . d\phi . dr$$

hence

$$D_p = KS\int_0^r\int_0^{2\pi}\int_0^{\pi/2}\cos\theta d\theta d\phi e^{-\mu r}dr$$

$$D_p = \frac{2\pi KS}{\mu}(1 - e^{-\mu r})$$

For C-11, N-13 and O-15 we use the k factor for 0.5 MeV photons, which Barbier gives as follows:

K 0.515 rem/h per Ci at 1m.

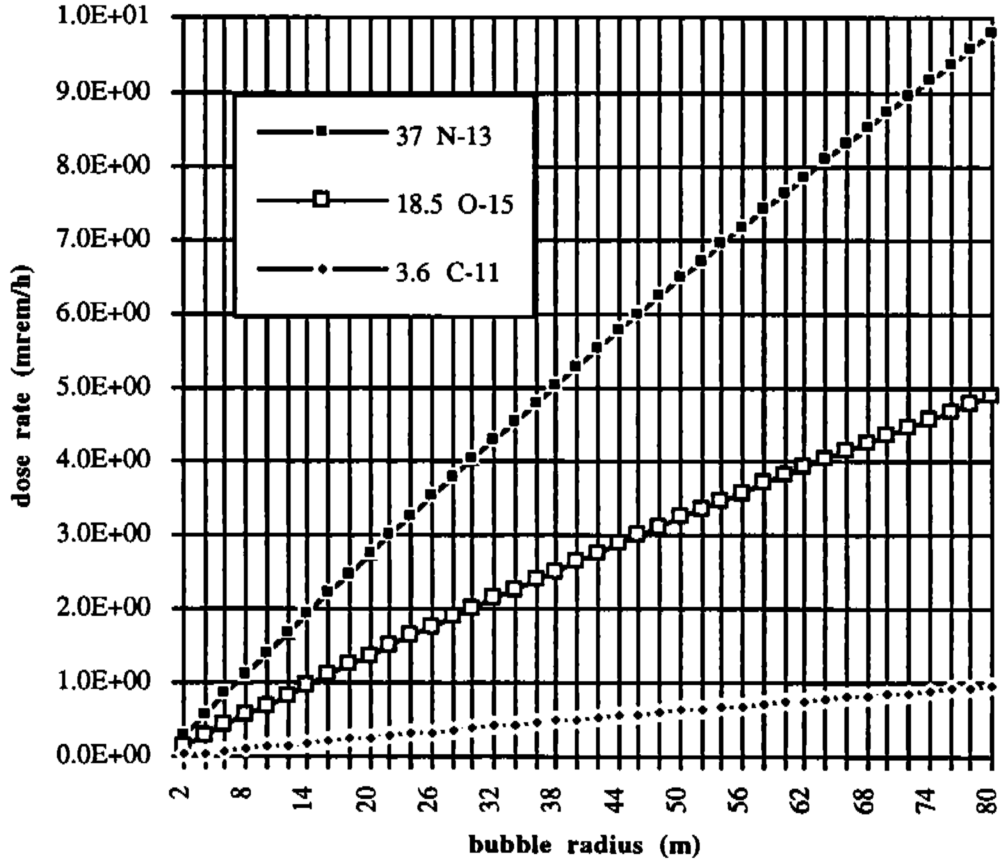
and for the other parameters:

μ 3.85 10^{-3} m^{-1} (derived from energy balance calculations for an infinite cloud)

S equals S_0

(C-11 4.3 10^{-6} Ci/m^3), (N-13 4.4 10^{-5} Ci/m^3), (O-15 2.2 10^{-5} Ci/m^3)

Dose rate at center of hemispherical cloud at constant specific activity (maximum values given in box)



The above figure shows that for a radius approximating to the size of the end station (approx. 20 m) the dose rate for N-13 (the highest values) is little more than 1 DAC, considerably less than the maximum value of about 15 DAC's.

Let us now consider a case where a person is standing just by the air exhaust port with the radioactive air expanding in a bubble all over the top and the (unrealistically) there is no mixing of air so that the radionuclides decay as the bubble expands.

Now because we assume that the radionuclides decay as the bubble expands, then

$$S = S_0 e^{-\lambda t}$$

Let L be the rate of air loss from the hall, then:

$$t = \frac{2\pi}{3L} r^3$$

Therefore

$$S = S_0 \exp\left(-\lambda \frac{2\pi}{3L} r^3\right)$$

and the dose at P becomes

$$\frac{K S_0 dV}{r^2} \exp\left(-\lambda \frac{2\pi}{3L} r^3\right) \exp(-\mu r)$$

hence

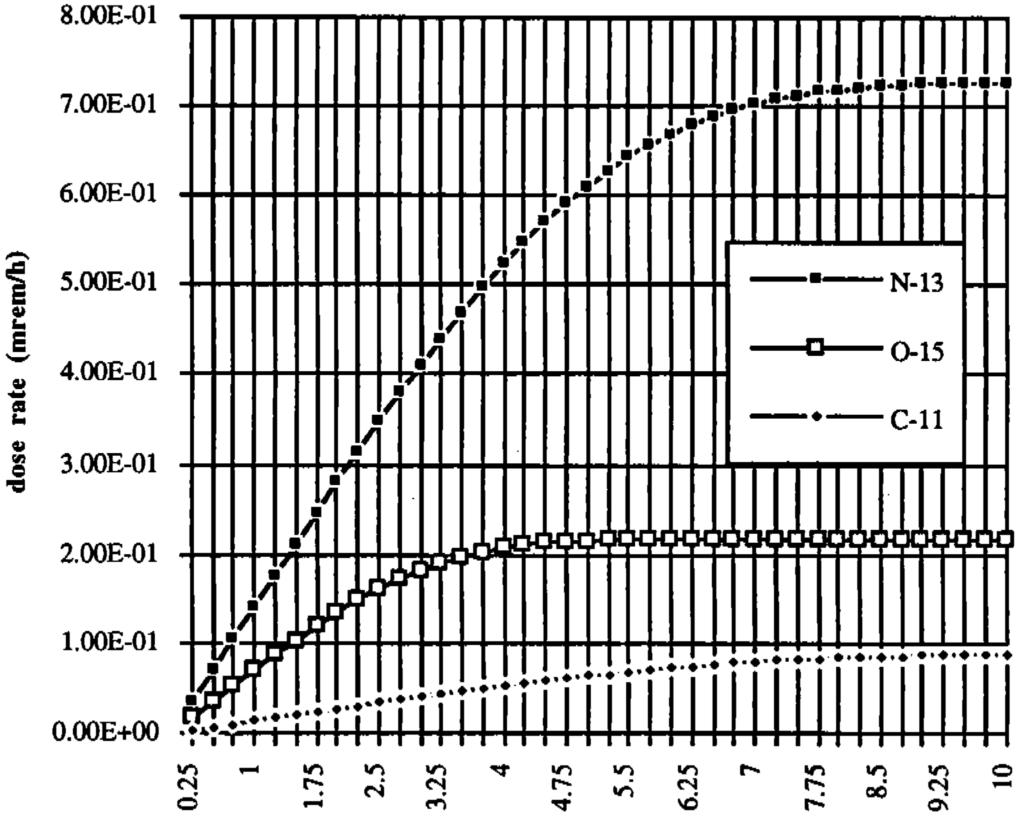
$$D_p = K S_0 \int_0^r \int_0^{2\pi} \int_0^{\pi/2} \cos\theta \exp\left(-\lambda \frac{2\pi}{3L} r^3\right) \exp(-\mu r) d\theta d\phi dr$$

which becomes

$$D_p = 2\pi K S_0 \int_0^r \exp\left(-\lambda \frac{2\pi}{3L} r^3\right) \exp(-\mu r) dr$$

Taking L to be 28 $m^3\ min^{-1}$ and with the other variables the same as before we can now solve this integral over r numerically (INTAIR.FOR)

Dose rate at center of hemispherical cloud versus cloud radius (including decay)



The graph gives the result of this calculation from which it can be seen that the maximum dose rate arises from a hemispherical cloud far smaller than a semi infinite cloud (a semi infinite cloud has to be greater than a few photon mean free paths) and the corresponding dose rates are much smaller. For the nuclide giving the greatest dose rate (N-13) we observe a maximum dose rate of about 0.7 mrem/h which is less than a third of a DAC.

Although the foregoing calculation is by no means realistic it does provide a model which demonstrates that for short lived radionuclides which are normally controlled on immersion dose rates great care must be taken not to be overly conservative in calculation. A consequence of this analysis is the need to examine whether the limiting dose rate has been transferred to the positron dose. However, for C-11 (the only radio nuclide given in ICRP-30 with inhalation data) the DAC (inhal) is given as 2 10^7 Bq/m^3. We must therefore attempt to determine the dose to the skin from positrons.

To complete this section on occupational exposures we estimate the dose to the skin from positrons using the immersion energy balance method which results in the approximate expression:

$$\dot{D}_\beta \cong 2CE$$

where $\dot{D}_\beta$ beta dose rate (rad/h)
C specific activity (μCi/g)
E energy (MeV)

Thus for air, and converting to rads per 2000 hours working year, and C to Bq/m^3 the equation becomes:

$$\dot{D}_\beta = 9 \times 10^{-5}\, CE\ (rad\ /\ y)$$

Thus for the concentrations given in table 2., column 6 and the listed average positron energies we obtain the un-corrected data for skin dose given in column 5 of table 3. The un-corrected data omits the correction for absorption in the basal layer approximately 70 μm below the surface and for 2π geometry. The correction uses the following equation:

$$\dot{H}_\beta = 0.5\exp(-\mu l)\dot{D}_\beta Q$$

where: μ absorption coeff in tissue (cm^{-1})
l thickness of epidermal layer (7 10^{-3} cm)
Q qual factor (taken to be 1 for betas)

The constant 0.5 converts from 4π to 2π since the electrons cannot penetrate the body.

Table 3. Estimation of skin dose from hall C concentrations given in table 2

nuclide	$\bar{E}_\beta$ MeV	approx μ cm^{-1}	av conc in hall Bq/m^3 (sat)	rad/yr (un-corrected)	rem/yr (corrected)
C-11	0.385	10	1.58E+05	5.5	2.5
N-13	0.491	7	1.61E+06	71	34
O-15	0.734	4	8.27E+05	55	27

We see therefore that the skin dose becomes limiting for an annual limit of exposure to the skin of 50 rem. It is also limiting for the lens of the eye for which the limit is 15 rem/year.

Exposure to the surrounding population

The final calculation studies the impact of the release of radio activated material on the surrounding population. For this exercise we use the computer code CAP88, which is the approved methodology utilizing a Gaussian plume model with all the appropriate meteorological, geographic and demographic data for the local area supplied.

As stated in the introduction to this note, TN# 94-0031 lists the calculated dose to the maximally exposed member of the general population as 4.75E-05 mrem/yr from hall operation. The assumptions in that note include no exhaust of radioactivity during operations and the presence of a He filled channel for transporting beam from the target chamber to the beam dump.

Adding the radioactivity generated and purged during one day of operation at 1.6 GeV and 10μA (16kW) under conditions of continuous release with no He bag to the annual source term identified in TN # 94-0031 the corresponding calculated dose to the maximally exposed member of the general population is 3.59E-03 mrem/yr - a increase of a factor of about 75 and a technical "violation " of the terms of our current NESHAP permit.

Operation for only 5 days under the conditions mentioned above results in a calculated dose to the maximally exposed member of the general population as 0.02 mrem/yr . At 0.1

mrem /yr calculated, the federal regulations require development of a process to conduct routine confirming measurements of the source term and regular reporting of the results (meaning more people, more money for equipment, and more auditors).

Conclusions

Although one can see that the occupational radiation dose associated with a reasonable model of the airborne radioactivity around the accelerator under the conditions mentioned above are relatively benign for short periods of operation, certain limits placed on us as a result of federal regulations and permitting requirements are not. The impact of such operations on a short term basis are chiefly a result of 10CFR835 posting, labeling, and exposure control requirements and 40CFR61 permitting requirements.

Prolonged operations without a He bag and with continuous venting would require significant changes to the radiation control program including an ALARA review for increased environmental release, a new NESHAP permit, and the development of means to measure and track the release.

To conclude, operations without a He bag installed downstream of the scattering chamber cannot be recommended neither can they be approved at the present time.

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 500 Meters South
Lifetime Fatal Cancer Risk: 4.27E-07

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Dose Equivalent (mrem/y)
GONADS	2.03E-02
BREAST	1.88E-02
R MAR	1.55E-02
LUNGS	1.79E-02
THYROID	1.88E-02
ENDOST	1.75E-02
RMNDR	1.53E-02
EFFEC	1.76E-02

RADIONUCLIDE EMISSIONS DURING THE YEAR 95

Nuclide	Class	Size	Source #1 Ci/y	TOTAL Ci/y
H-3	*	0.00	6.6E-09	6.6E-09
BE-7	Y	1.00	6.9E-06	6.9E-06
C-11	D	1.00	8.4E-01	8.4E-01
N-13	D	1.00	8.6E+00	8.6E+00
O-15	D	1.00	4.5E+00	4.5E+00
AR-41	*	0.00	0.0E+00	0.0E+00
BR-84		0.00	5.9E-01	5.9E-01

SITE INFORMATION

Temperature: 15 degrees C
Precipitation: 110 cm/y
Mixing Height: 950 m

SOURCE INFORMATION

Source Number: 1

Stack Height (m): 2.00
Diameter (m): 0.30

Plume Rise
Momentum (m/s): 6.60E+00
(Exit Velocity)

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	0.076	0.000	0.008
Fraction From Assessment Area:	0.924	1.000	0.992
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

500 800 1000 1500 2000 3000 4000 5000 8000 10000

Table 1 Estimated Yields of Radionuclides from Photoactivated Air
(Swanson's published figures given in the last column)

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Cl - 39	Ar	40	1.30E-02	(g, p)	0.5	8.5E+06	8.5E+06	1.5E+06

Using the data in column 8 of table 1 and the following data:

air removal rate R	1000 cfm (28 m^3 min^{-1}) for hall C
volume of hall C	2.7 10^4 m^3
hence λ_{vent}	10^{-3} min^{-1}
beam power	16 kW (1.6 GeV @ 10 μA)*
length of beam path	25 m of air

we obtain the reduced saturation levels set out in table 2.

Table 2. Approximate Release Rates for the Relevent Radio nuclides

radio nuclide	lamda dec 1/min	lamda vent 1/min	nucl tot prod'n Bq/kW.m	reduced sat Bq	av conc in hall Bq/m3 (sat)	act rel'ed per day Ci (sat)	act rel'ed per day Ci (1day radn)	act rel'ed per day Ci (5 day radn)
H - 3	1.07E-07	1.00E-03	7.10E+06	3.04E+05	1.13E+01	1.23E-05	1.00E-09	1.31E-09
Be - 7	8.90E-06	1.00E-03	1.10E+06	3.88E+06	1.44E+02	1.57E-04	1.06E-06	1.38E-06
C - 11	0.0338	1.00E-03	1.10E+07	4.27E+09	1.58E+05	1.72E-01	1.68E-01	1.68E-01
N - 13	0.0693	1.00E-03	1.10E+08	4.34E+10	1.61E+06	1.75E+00	1.73E+00	1.73E+00
O - 15	0.33	1.00E-03	5.60E+07	2.23E+10	8.27E+05	9.01E-01	8.99E-01	8.99E-01
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We note that for saturation values i.e., long irradiation times the release rates for the long half life radionuclides is much larger (column 7) than for the short irradiation times (columns 8 & 9). However, the short half life radionuclides C-11, N-13 and O-15 are seen to be close to saturation after a very short irradiation period.

What can we say about the likely dose rates to people who enter the hall immediately after shut-down and anyone standing in the exhaut plume?

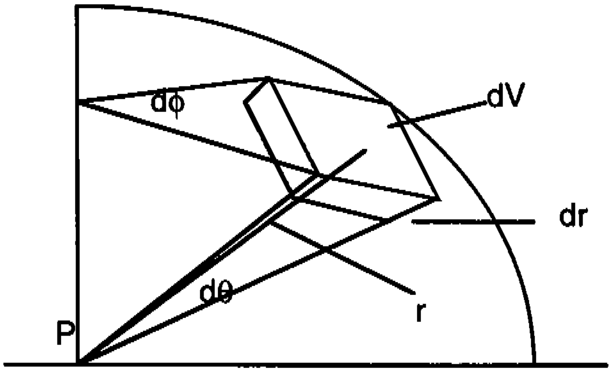
On the basis of the current regulation we are not allowed to take credit from immersion exposure in anything other than a semi nfinite cloud, although because of decay it is

---

*

impossible to achieve an infinite cloud of the short half life radionuclides in the volume specified[1]. Thus taking a one day irradiation time we note that the occupational exposure must be taken as about 15 DAC's (derived air concentrations).

Another, more realistic model, assumes a large hemispherical bubble of air over the person in the hall. We now calculate the maximum dose rate to a person standing in the middle of the hemispherical bubble on the assumption there is perfect mixing. From the figure below:



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SdV = activity in vol element dV
K= k factor (dose rate rem/h at 1 m per curie)

dose at P due to SdV is given by:

$$\frac{KSdV}{r^2}e^{-\mu r}$$

where μ is some photon attenuation coefficient in air,

Now

$$dV = rd\theta . r\cos\theta . d\phi . dr$$

hence

$$D_p = KS\int_0^r\int_0^{2\pi}\int_0^{\pi/2}\cos\theta d\theta d\phi e^{-\mu r}dr$$

$$D_p = \frac{2\pi KS}{\mu}(1-e^{-\mu r})$$

For C-11, N-13 and O-15 we use the k factor for 0.5 MeV photons, which Barbier gives as follows:

K 0.515 rem/h per Ci at 1m.

and for the other parameters:

μ $3.85\ 10^{-3}\ m^{-1}$

S equals S_0

(C-11 $4.3\ 10^{-6}\ Ci/m^3$), (N-13 $4.4\ 10^{-5}\ Ci/m^3$), (O-15 $2.2\ 10^{-5}\ Ci/m^3$)

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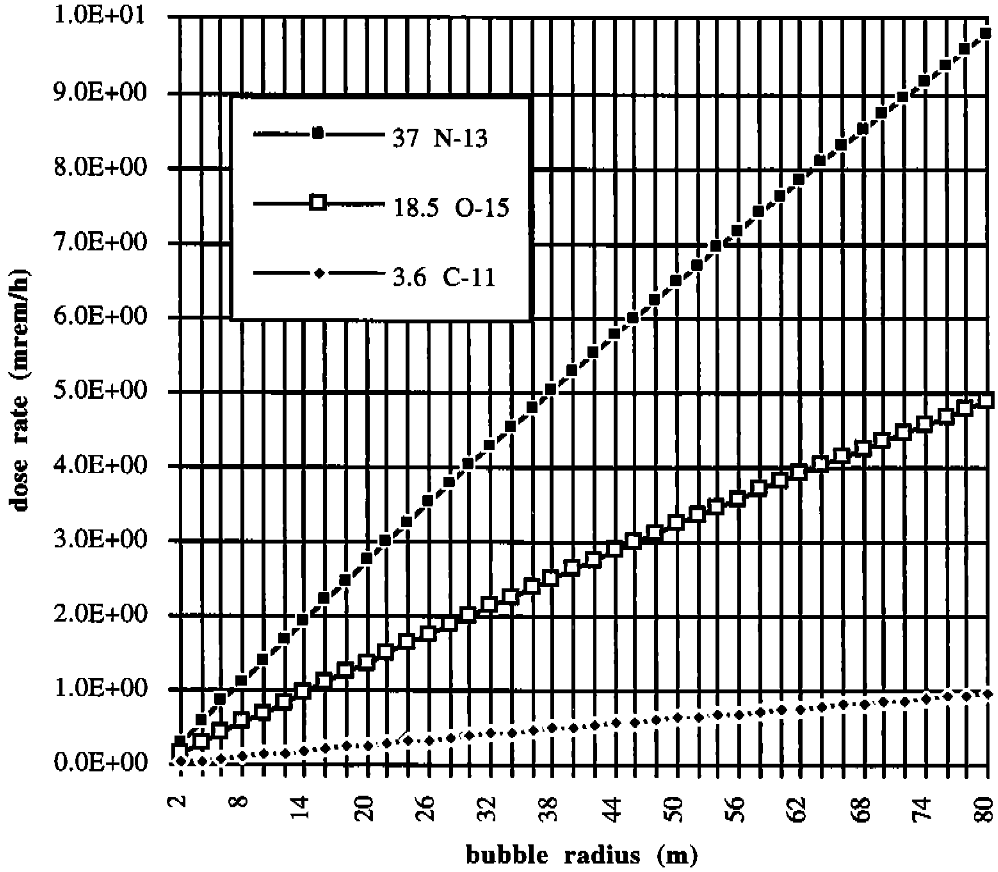
[1]Here we have an example of regulation requiring us to do a phyically inappropriate calculation.

Dose rate at center of hemispherical cloud at constant specific activity (maximum values given in box)



The above figure shows that for a radius approximating to the size of the end station (approx 20 m) the dose rate for N-13 (the highest values) is little more than 1 DAC, considerably less than the maximum value of about 15 DAC's.

Let us now consider a case where a person is standing just by the air exhaust port with the radioactive air expanding in a bubble all over the top and the (unrealistically) there is no mixing of air so that the radionuclides decay as the bubble expands.

Now because we assume that the radionuclides decay as the bubble expands, then

$$S = S_0 e^{-\lambda t}$$

Let L be the rate of air loss from the hall, then:

$$t = \frac{2\pi}{3L} r^3$$

Therefore

$$S = S_0 \exp\left(-\lambda \frac{2\pi}{3L} r^3\right)$$

and the dose at P becomes

$$\frac{KS_0 dV}{r^2}\exp\left(-\lambda\frac{2\pi}{3L}r^3\right)\exp(-\mu r)$$

hence

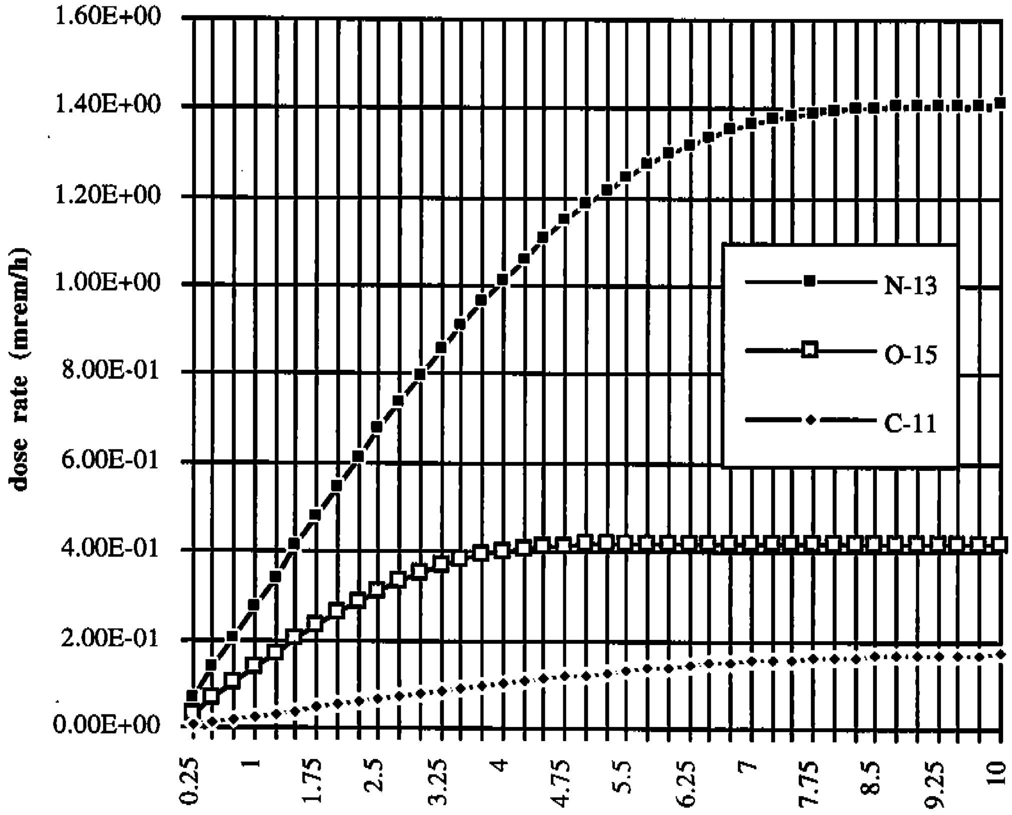
$$D_p = KS_0\int_0^r\int_0^{2\pi}\int_0^{\pi/2}\cos\theta\exp\left(-\lambda\frac{2\pi}{3L}r^3\right)\exp(-\mu r)d\theta d\phi dr$$

which becomes

$$D_p = 2\pi KS_0\int_0^r\exp\left(-\lambda\frac{2\pi}{3L}r^3\right)\exp(-\mu r)dr$$

Taking L to be 28 $m^3\ min^{-1}$ and with the other variables the same as before we can now solve this integral over r numerically (INTAIR.FOR)

Dose rate at center of hemispherical cloud versus cloud radius (including decay)



The graph gives the result of this calculation from which it can be seen that the maximum dose rate arises from a hemispherical cloud far smaller than a semi infinite cloud (a semi infinite cloud has to be greater than a few photon mean free paths) and the corresponding dose rates are much smaller. For the nuclide giving the greatest dose rate (N-13) we observe a maximum dose rate of about 1.4 mrem/h which is not much greater than half a DAC.

Although the foregoing calculation is by no means realistic it does provide a model which demonstrates that for short lived radionuclides which are normally controlled on immersion dose rates great care must be taken not to be overly conservative in calculation. A consequence of this analysis is the need to examine whether the limiting dose rate has been transferred to the positron dose. However, for C-11 (the only radio nuclide given in ICRP-30 with inhalation data) the DAC (inhal) is given as 2 10^7 Bq/m^3.

do not
copy this
part

Infor for
Bob only!

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 500 Meters South
Lifetime Fatal Cancer Risk: 8.73E-08

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Dose Equivalent (mrem/y)
GONADS	4.14E-03
BREAST	3.84E-03
R MAR	3.16E-03
LUNGS	3.67E-03
THYROID	3.84E-03
ENDOST	3.58E-03
RMNDR	3.13E-03
EFFEC	3.59E-03

RADIONUCLIDE EMISSIONS DURING THE YEAR 95

		Source		
		#1	TOTAL	
Nuclide	Class	Size	Ci/y	Ci/y
H-3	*	0.00	5.1E-03	5.1E-03
BE-7	Y	1.00	2.6E-03	2.6E-03
C-11	D	1.00	1.7E-01	1.7E-01
N-13	D	1.00	1.7E+00	1.7E+00
O-15	D	1.00	9.0E-01	9.0E-01
AR-41	*	0.00	8.6E-04	8.6E-04
BR-84		0.00	1.3E-01	1.3E-01

SITE INFORMATION

Temperature: 15 degrees C
Precipitation: 110 cm/y
Mixing Height: 950 m

SOURCE INFORMATION

Source Number: 1

Stack Height (m): 2.00
Diameter (m): 0.30

Plume Rise
Momentum (m/s): 6.60E+00
(Exit Velocity)

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	0.076	0.000	0.008
Fraction From Assessment Area:	0.924	1.000	0.992
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

500 800 1000 1500 2000 3000 4000 5000 8000 10000

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SYNOPSIS REPORT

Non-Radon Individual Assessment
Nov 17, 1995 12:30 am

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA Zip: 23464

Effective Dose Equivalent (mrem/year)
3.59E-03

was 4.75×10^{-5}

1 day

End Station compliment only ref TN # 94-031

At This Location: 500 Meters South

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF++.DAT
Dataset Date: Nov 17, 1995 12:30 am
Wind File: WNDFILES\CEBAF.WND

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W E A T H E R   D A T A

Non-Radon Individual Assessment
Nov 17, 1995 12:30 am

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA Zip: 23464

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF++.DAT
Dataset Date: Nov 17, 1995 12:30 am
Wind File: WNDFILES\CEBAF.WND

HARMONIC AVERAGE WIND SPEEDS (WIND TOWARDS)

Pasquill Stability Class

Dir	A	B	C	D	E	F	G	Wind Frequency
N	0.863	0.994	1.578	2.864	2.572	0.775	0.000	0.078
NNW	0.863	1.013	1.300	2.159	2.572	0.772	0.000	0.028
NW	0.878	1.033	1.137	1.919	2.572	0.776	0.000	0.031
WNW	0.952	1.004	1.495	1.878	2.572	0.772	0.000	0.038
W	0.772	1.074	1.305	2.215	2.585	0.775	0.772	0.062
WSW	0.000	1.212	1.552	2.766	2.572	0.772	0.000	0.052
SW	1.029	1.129	1.639	2.804	2.593	0.772	0.000	0.068
SSW	0.887	1.075	1.650	3.308	2.581	0.782	0.000	0.095
S	0.795	0.989	1.427	3.301	2.598	0.772	0.772	0.132
SSE	0.772	1.090	1.310	2.839	2.635	0.772	0.000	0.040
SE	0.952	0.911	1.268	2.318	2.572	0.772	0.772	0.034
ESE	0.826	0.968	1.058	2.122	2.589	0.778	0.000	0.035
E	0.944	1.018	1.345	2.516	2.584	0.772	0.772	0.053
ENE	1.038	1.150	2.005	3.270	2.572	0.779	0.772	0.061
NE	0.899	1.166	1.900	3.435	2.579	0.772	0.000	0.094
NNE	0.795	1.147	1.797	3.585	2.572	0.776	0.000	0.098

ARITHMETIC AVERAGE WIND SPEEDS (WIND TOWARDS)

Pasquill Stability Class

Dir	A	B	C	D	E	F	G
N	1.043	1.431	2.736	4.360	2.572	0.784	0.000
NNW	1.043	1.529	2.369	3.599	2.572	0.772	0.000
NW	1.082	1.530	1.787	3.196	2.572	0.787	0.000
WNW	1.260	1.486	2.473	3.155	2.572	0.772	0.000
W	0.772	1.496	2.232	3.718	2.593	0.783	0.772
WSW	0.000	1.950	2.694	4.375	2.572	0.772	0.000
SW	1.415	1.709	2.828	4.452	2.606	0.772	0.000
SSW	1.107	1.578	2.848	5.165	2.587	0.805	0.000
S	0.849	1.422	2.456	5.228	2.615	0.772	0.772

C.*

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Clean Air Act Assessment Package - 1988

SYNOPSIS REPORT

Non-Radon Individual Assessment
Nov 17, 1995 1:03 pm

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA Zip: 23464

Effective Dose Equivalent
(mrem/year)

5 days only no He-bag

1.76E-02

At This Location: 500 Meters South

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF+.DAT
Dataset Date: Nov 17, 1995 1:03 pm
Wind File: WNDFILES\CEBAF.WND

SSE	0.772	1.733	2.135	4.615	2.676	0.772	0.000
SE	1.260	1.166	2.178	4.030	2.572	0.772	0.772
ESE	0.941	1.398	1.662	3.776	2.601	0.794	0.000
E	1.241	1.485	2.459	4.190	2.593	0.772	0.772
ENE	1.432	1.913	3.317	4.808	2.572	0.795	0.772
NE	1.135	1.856	3.207	5.004	2.584	0.772	0.000
NNE	0.849	1.775	3.072	4.914	2.572	0.786	0.000

FREQUENCIES OF STABILITY CLASSES (WIND TOWARDS)

Pasquill Stability Class

Dir	A	B	C	D	E	F	G
N	0.0093	0.0478	0.0799	0.6329	0.1393	0.0907	0.0000
NNW	0.0258	0.0579	0.0823	0.5286	0.1600	0.1455	0.0000
NW	0.0094	0.0495	0.0665	0.5181	0.1681	0.1883	0.0000
WNW	0.0153	0.0518	0.0752	0.4882	0.2148	0.1547	0.0000
W	0.0024	0.0273	0.0556	0.6354	0.1522	0.1258	0.0013
WSW	0.0000	0.0376	0.0708	0.7110	0.1195	0.0611	0.0000
SW	0.0021	0.0284	0.0781	0.7355	0.0858	0.0701	0.0000
SSW	0.0062	0.0211	0.0474	0.7985	0.0652	0.0616	0.0000
S	0.0089	0.0210	0.0482	0.8372	0.0351	0.0484	0.0012
SSE	0.0037	0.0369	0.0760	0.7727	0.0474	0.0633	0.0000
SE	0.0174	0.0497	0.0656	0.7454	0.0603	0.0592	0.0024
ESE	0.0336	0.0652	0.1034	0.5915	0.0905	0.1158	0.0000
E	0.0302	0.0650	0.1050	0.5993	0.0821	0.1169	0.0015
ENE	0.0049	0.0947	0.1258	0.6352	0.0754	0.0627	0.0013
NE	0.0248	0.0500	0.1230	0.6797	0.0817	0.0409	0.0000
NNE	0.0119	0.0346	0.0983	0.6915	0.1015	0.0622	0.0000
TOT	0.0117	0.0420	0.0802	0.6912	0.0948	0.0795	0.0005

ADDITIONAL WEATHER INFORMATION

Average Air Temperature: 15.0 degrees C
288.2 K
Precipitation: 110.0 cm/y
Lid Height: 950 meters
Surface Roughness Length: 0.010 meters
Height Of Wind Measurements: 10.0 meters
Average Wind Speed: 3.783 m/s

Vertical Temperature Gradients:
STABILITY E 0.073 k/m
STABILITY F 0.109 k/m
STABILITY G 0.146 k/m

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Clean Air Act Assessment Package - 1988

D O S E A N D R I S K E Q U I V A L E N T S U M M A R I E S

Non-Radon Individual Assessment
Nov 17, 1995 12:30 am

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA Zip: 23464

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF++.DAT
Dataset Date: Nov 17, 1995 12:30 am
Wind File: WNDFILES\CEBAF.WND

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Selected Individual (mrem/y)
GONADS	4.14E-03
BREAST	3.84E-03
R MAR	3.16E-03
LUNGS	3.67E-03
THYROID	3.84E-03
ENDOST	3.58E-03
RMNDR	3.13E-03
EFFEC	3.59E-03

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	3.14E-06
INHALATION	9.02E-05
AIR IMMERSION	3.40E-03
GROUND SURFACE	1.01E-04
INTERNAL	9.33E-05
EXTERNAL	3.50E-03
TOTAL	3.59E-03

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
H-3	3.88E-06
BE-7	3.49E-05
C-11	2.70E-04
N-13	2.30E-03
O-15	5.62E-04
AR-41	1.96E-06
BR-84	4.22E-04
TOTAL	3.59E-03

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
LEUKEMIA	1.00E-08
BONE	6.33E-10
THYROID	1.75E-09
BREAST	1.50E-08
LUNG	1.79E-08
STOMACH	9.74E-09
BOWEL	4.61E-09
LIVER	1.02E-08
PANCREAS	6.14E-09
URINARY	3.80E-09
OTHER	7.51E-09
TOTAL	8.73E-08

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	6.59E-11
INHALATION	3.48E-09
AIR IMMERSION	8.14E-08
GROUND SURFACE	2.41E-09
INTERNAL	3.55E-09
EXTERNAL	8.38E-08
TOTAL	8.73E-08

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
H-3	1.06E-10
BE-7	8.78E-10
C-11	6.68E-09
N-13	5.58E-08
O-15	1.35E-08
AR-41	4.75E-11
BR-84	1.03E-08
TOTAL	8.73E-08

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	500	800	1000	1500	2000	3000	4000
N	2.6E-03	9.2E-04	5.5E-04	2.1E-04	1.1E-04	4.1E-05	2.2E-05
NNW	1.1E-03	4.0E-04	2.3E-04	8.7E-05	4.3E-05	1.6E-05	9.0E-06
NW	1.4E-03	4.8E-04	2.7E-04	1.0E-04	4.9E-05	1.8E-05	9.6E-06
WNW	1.6E-03	5.7E-04	3.3E-04	1.2E-04	6.0E-05	2.2E-05	1.1E-05
W	2.5E-03	8.7E-04	5.1E-04	2.0E-04	9.7E-05	3.6E-05	1.9E-05
WSW	1.6E-03	5.9E-04	3.5E-04	1.4E-04	7.3E-05	2.9E-05	1.6E-05
SW	2.1E-03	7.7E-04	4.6E-04	1.8E-04	9.5E-05	3.7E-05	2.0E-05
SSW	2.7E-03	1.0E-03	6.0E-04	2.5E-04	1.3E-04	5.1E-05	2.7E-05
S	3.6E-03	1.3E-03	8.0E-04	3.3E-04	1.7E-04	6.9E-05	3.7E-05
SSE	1.2E-03	4.4E-04	2.7E-04	1.1E-04	5.6E-05	2.3E-05	1.3E-05
SE	1.1E-03	4.1E-04	2.4E-04	9.8E-05	5.1E-05	2.0E-05	1.1E-05
ESE	1.3E-03	4.6E-04	2.7E-04	1.0E-04	5.1E-05	2.0E-05	1.1E-05
E	1.9E-03	6.6E-04	3.9E-04	1.5E-04	7.4E-05	2.8E-05	1.5E-05
ENE	1.7E-03	6.2E-04	3.7E-04	1.5E-04	7.6E-05	3.0E-05	1.6E-05
NE	2.4E-03	8.8E-04	5.3E-04	2.2E-04	1.1E-04	4.5E-05	2.4E-05
NNE	2.7E-03	9.8E-04	5.9E-04	2.4E-04	1.2E-04	4.7E-05	2.5E-05

	Distance (m)		
Direction	5000	8000	10000
N	1.3E-05	5.3E-06	3.8E-06
NNW	6.0E-06	3.2E-06	2.7E-06
NW	6.3E-06	3.3E-06	2.7E-06
WNW	7.3E-06	3.5E-06	2.9E-06
W	1.1E-05	4.7E-06	3.5E-06
WSW	1.0E-05	4.4E-06	3.3E-06
SW	1.2E-05	5.1E-06	3.7E-06
SSW	1.7E-05	6.7E-06	4.6E-06
S	2.3E-05	8.6E-06	5.7E-06
SSE	8.4E-06	4.0E-06	3.1E-06
SE	7.5E-06	3.7E-06	3.0E-06
ESE	7.0E-06	3.6E-06	2.9E-06
E	9.5E-06	4.3E-06	3.3E-06
ENE	1.0E-05	4.5E-06	3.4E-06
NE	1.5E-05	6.0E-06	4.2E-06
NNE	1.5E-05	6.0E-06	4.2E-06

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)						
Direction	500	800	1000	1500	2000	3000	4000
N	6.3E-08	2.2E-08	1.3E-08	5.2E-09	2.6E-09	9.9E-10	5.2E-10
NNW	2.8E-08	9.6E-09	5.6E-09	2.1E-09	1.0E-09	3.9E-10	2.1E-10
NW	3.4E-08	1.2E-08	6.7E-09	2.5E-09	1.2E-09	4.3E-10	2.3E-10
WNW	4.0E-08	1.4E-08	8.0E-09	3.0E-09	1.5E-09	5.3E-10	2.7E-10
W	6.0E-08	2.1E-08	1.2E-08	4.8E-09	2.4E-09	8.7E-10	4.5E-10
WSW	4.0E-08	1.4E-08	8.5E-09	3.5E-09	1.8E-09	7.0E-10	3.8E-10
SW	5.2E-08	1.9E-08	1.1E-08	4.5E-09	2.3E-09	9.0E-10	4.8E-10
SSW	6.6E-08	2.4E-08	1.5E-08	6.0E-09	3.1E-09	1.2E-09	6.6E-10
S	8.7E-08	3.2E-08	2.0E-08	8.1E-09	4.2E-09	1.7E-09	9.0E-10
SSE	3.0E-08	1.1E-08	6.5E-09	2.6E-09	1.4E-09	5.5E-10	3.0E-10
SE	2.7E-08	9.9E-09	5.9E-09	2.4E-09	1.2E-09	4.9E-10	2.7E-10
ESE	3.2E-08	1.1E-08	6.5E-09	2.5E-09	1.2E-09	4.7E-10	2.6E-10
E	4.6E-08	1.6E-08	9.5E-09	3.6E-09	1.8E-09	6.8E-10	3.6E-10
ENE	4.2E-08	1.5E-08	9.0E-09	3.6E-09	1.8E-09	7.2E-10	3.9E-10
NE	5.9E-08	2.1E-08	1.3E-08	5.3E-09	2.8E-09	1.1E-09	5.8E-10
NNE	6.6E-08	2.4E-08	1.4E-08	5.8E-09	3.0E-09	1.1E-09	6.1E-10

	Distance (m)		
Direction	5000	8000	10000
N	3.2E-10	1.2E-10	8.7E-11
NNW	1.4E-10	7.2E-11	6.0E-11
NW	1.5E-10	7.4E-11	6.1E-11
WNW	1.7E-10	8.0E-11	6.4E-11
W	2.7E-10	1.1E-10	8.0E-11
WSW	2.4E-10	1.0E-10	7.6E-11
SW	3.0E-10	1.2E-10	8.5E-11
SSW	4.1E-10	1.6E-10	1.1E-10
S	5.6E-10	2.0E-10	1.3E-10
SSE	2.0E-10	9.1E-11	7.1E-11
SE	1.8E-10	8.4E-11	6.7E-11
ESE	1.7E-10	8.1E-11	6.5E-11
E	2.3E-10	9.8E-11	7.4E-11
ENE	2.4E-10	1.0E-10	7.8E-11
NE	3.6E-10	1.4E-10	9.6E-11
NNE	3.7E-10	1.4E-10	9.7E-11

C A P 8 8 - P C

Version 1.00

Clean Air Act Assessment Package - 1988

G E N E R A L   D A T A

Non-Radon Individual Assessment
Nov 17, 1995 12:30 am

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA   Zip: 23464

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF++.DAT
Dataset Date: Nov 17, 1995 12:30 am
Wind File: WNDFILES\CEBAF.WND

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

Nuclide	Clearance Class	Particle Size (microns)	Scavenging Coefficient (per second)	Dry Deposition Velocity (m/s)
H-3	*	0.0	0.00E+00	0.00E+00
BE-7	Y	1.0	1.10E-05	1.80E-03
C-11	D	1.0	1.10E-05	1.80E-03
N-13	D	1.0	1.10E-05	1.80E-03
O-15	D	1.0	1.10E-05	1.80E-03
AR-41	*	0.0	0.00E+00	0.00E+00
BR-84		0.0	1.10E-05	1.80E-03

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

Nuclide	DECAY CONSTANT (PER DAY) Radio-active (1)	Surface	Water	TRANSFER COEFFICIENT Milk (2)	Meat (3)
H-3	0.00E+00	5.48E-05	0.00E+00	0.00E+00	0.00E+00
BE-7	1.30E-02	5.48E-05	0.00E+00	9.00E-07	1.00E-03
C-11	4.87E+01	5.48E-05	0.00E+00	0.00E+00	0.00E+00
N-13	1.00E+02	5.48E-05	0.00E+00	2.50E-02	7.50E-02
O-15	4.90E+02	5.48E-05	0.00E+00	0.00E+00	0.00E+00
AR-41	9.10E+00	5.48E-05	0.00E+00	0.00E+00	0.00E+00
BR-84	3.14E+01	5.48E-05	0.00E+00	2.00E-02	2.50E-02

FOOTNOTES: (1) Effective radioactive decay constant in plume; set to zero if less than 1.0E-2

(2) Fraction of animal's daily intake of nuclide which appears in each L of milk (days/L)

(3) Fraction of animal's daily intake of nuclide which appears in each kg of meat (days/kg)

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

	CONCENTRATION UPTAKE FACTOR		GI UPTAKE FRACTION	
Nuclide	Forage (1)	Edible (2)	Inhalation	Ingestion
H-3	0.00E+00	0.00E+00	9.50E-01	9.50E-01
BE-7	1.00E-02	6.42E-04	5.00E-03	5.00E-03
C-11	0.00E+00	0.00E+00	9.50E-01	9.50E-01
N-13	3.00E+01	1.28E+01	9.50E-01	9.50E-01
O-15	0.00E+00	0.00E+00	9.50E-01	9.50E-01
AR-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BR-84	1.50E+00	6.42E-01	0.00E+00	0.00E+00

FOOTNOTES: (1) Concentration factor for uptake of nuclide from soil for pasture and forage (in pCi/kg dry weight per pCi/kg dry soil)

(2) Concentration factor for uptake of nuclide from soil by edible parts of crops (in pCi/kg wet weight per pCi/kg dry soil)

H-3 DOSE CONVERSION FACTOR FOR WATER INGESTION (rem-cc/pCi-y): 5.70E-02

VALUES FOR RADIONUCLIDE-INDEPENDENT PARAMETERS

HUMAN INHALATION RATE

Cubic centimeters/hr	9.17E+05

SOIL PARAMETERS

Effective surface density (kg/sq m, dry weight) (Assumes 15 cm plow layer)	2.15E+02

BUILDUP TIMES

For activity in soil (years)	1.00E+02
For radionuclides deposited on ground/water (days)	3.65E+04

DELAY TIMES

Ingestion of pasture grass by animals (hr)	0.00E+00
Ingestion of stored feed by animals (hr)	2.16E+03
Ingestion of leafy vegetables by man (hr)	3.36E+02
Ingestion of produce by man (hr)	3.36E+02
Transport time from animal feed-milk-man (day)	2.00E+00
Time from slaughter to consumption (day)	2.00E+01

WEATHERING

Removal rate constant for physical loss (per hr)	2.90E-03

CROP EXPOSURE DURATION

Pasture grass (hr)	7.20E+02
Crops/leafy vegetables (hr)	1.44E+03

AGRICULTURAL PRODUCTIVITY

Grass-cow-milk-man pathway (kg/sq m)	2.80E-01
Produce/leafy veg for human consumption (kg/sq m)	7.16E-01

FALLOUT INTERCEPTION FRACTIONS

Vegetables	2.00E-01
Pasture	5.70E-01

GRAZING PARAMETERS

Fraction of year animals graze on pasture	4.00E-01
Fraction of daily feed that is pasture grass when animal grazes on pasture	4.30E-01

VALUES FOR RADIONUCLIDE-INDEPENDENT PARAMETERS

ANIMAL FEED CONSUMPTION FACTORS	
Contaminated feed/forage (kg/day, dry weight)	1.56E+01
DAIRY PRODUCTIVITY	
Milk production of cow (L/day)	1.10E+01
MEAT ANIMAL SLAUGHTER PARAMETERS	
Muscle mass of animal at slaughter (kg)	2.00E+02
Fraction of herd slaughtered (per day)	3.81E-03
DECONTAMINATION	
Fraction of radioactivity retained after washing for leafy vegetables and produce	5.00E-01
FRACTIONS GROWN IN GARDEN OF INTEREST	
Produce ingested	1.00E+00
Leafy vegetables ingested	1.00E+00
INGESTION RATIOS:	
IMMEDIATE SURROUNDING AREA/TOTAL WITHIN AREA	
Vegetables	7.60E-02
Meat	8.00E-03
Milk	0.00E+00
MINIMUM INGESTION FRACTIONS FROM OUTSIDE AREA	
(Minimum fractions of food types from outside area listed below are actual fixed values.)	
Vegetables	0.00E+00
Meat	0.00E+00
Milk	0.00E+00
HUMAN FOOD UTILIZATION FACTORS	
Produce ingestion (kg/y)	1.76E+02
Milk ingestion (L/y)	1.12E+02
Meat ingestion (kg/y)	8.50E+01
Leafy vegetable ingestion (kg/y)	1.80E+01
SWIMMING PARAMETERS	
Fraction of time spent swimming	0.00E+00

Dilution factor for water (cm)	1.00E+00

CAP88-PC

Version 1.00

Clean Air Act Assessment Package - 1988

DOSE AND RISK CONVERSION FACTORS

Non-Radon Individual Assessment
Nov 17, 1995 12:30 am

Facility: Continuous Electron Beam Accelerator Facility
Address: Radiation Control Group, Mail Stop 12A1
12000 Jefferson Avenue
City: Newport News
State: VA Zip: 23464

Source Category: Department of Energy
Source Type: Stack
Emission Year: 95

Comments: Adds data for operation in Hall C with no He bag
10 uA and 1.6 GeV (16 kW), and 1000 cfm purge

Dataset Name: CEBAF++.DAT
Dataset Date: Nov 17, 1995 12:30 am
Wind File: WNDFILES\CEBAF.WND

DOSE AND RISK FACTOR UNITS

The units for each type of dose rate conversion factor are shown below, by pathway:

Pathway	Units
Ingestion	millirem/picoCurie
Inhalation	millirem/picoCurie
Immersion	millirem-cubic centimeter/microCurie-year
Surface	millirem-square centimeter/microCurie-year

Risks for internal exposures (inhalation and ingestion) are the lifetime risk of premature death in a birth cohort of 100,000 people for a 1 picoCurie/year intake rate, where the average lifetime is 70.7565 years. This is simplified to lifetime risk per 100,000 picoCuries.

The units for each type of risk conversion factor are shown below, by pathway:

Pathway	Units
Ingestion	lifetime risk/100,000 picoCuries
Inhalation	lifetime risk/100,000 picoCuries
Immersion	lifetime risk-cubic centimeter/100,000 picoCurie-years
Surface	lifetime risk-square centimeter/100,000 picoCurie-years

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* NUCLIDE H-3 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	8.300E-08	1.250E-07	0.000E+00	0.000E+00
BREAST	8.300E-08	1.250E-07	0.000E+00	0.000E+00
R MAR	8.260E-08	1.240E-07	0.000E+00	0.000E+00
LUNGS	8.360E-08	1.250E-07	0.000E+00	0.000E+00
THYROID	8.280E-08	1.240E-07	0.000E+00	0.000E+00
ENDOST	6.560E-08	9.850E-08	0.000E+00	0.000E+00
RMNDR	1.078E-07	1.326E-07	0.000E+00	0.000E+00
EFFEC	8.993E-08	1.263E-07	0.000E+00	0.000E+00

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	2.616E-08	3.927E-08	0.000E+00	0.000E+00
BONE	1.161E-09	1.743E-09	0.000E+00	0.000E+00
THYROID	3.766E-09	5.640E-09	0.000E+00	0.000E+00
BREAST	3.251E-08	4.896E-08	0.000E+00	0.000E+00
LUNG	4.145E-08	6.197E-08	0.000E+00	0.000E+00
STOMACH	3.511E-08	4.064E-08	0.000E+00	0.000E+00
BOWEL	1.927E-08	2.175E-08	0.000E+00	0.000E+00
LIVER	2.903E-08	4.347E-08	0.000E+00	0.000E+00
PANCREAS	1.972E-08	2.960E-08	0.000E+00	0.000E+00
URINARY	1.074E-08	1.619E-08	0.000E+00	0.000E+00
OTHER	2.411E-08	3.620E-08	0.000E+00	0.000E+00

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* NUCLIDE BE-7 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	2.100E-07	1.194E-07	2.904E+08	6.031E+04
BREAST	2.589E-08	1.435E-07	2.712E+08	5.624E+04
R MAR	4.567E-08	1.502E-07	2.216E+08	4.588E+04
LUNGS	5.260E-09	1.399E-06	2.161E+08	4.477E+04
THYROID	2.363E-09	1.167E-07	2.686E+08	5.587E+04
ENDOST	1.848E-08	1.117E-07	2.557E+08	5.291E+04
RMNDR	2.097E-07	2.716E-07	2.155E+08	4.477E+04
EFFEC	1.261E-07	3.257E-07	2.462E+08	5.109E+04

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	1.446E-08	4.755E-08	7.017E+01	1.453E-02
BONE	3.270E-10	1.976E-09	4.525E+00	9.364E-04
THYROID	1.074E-10	5.306E-09	1.222E+01	2.541E-03
BREAST	1.014E-08	5.616E-08	1.062E+02	2.203E-02
LUNG	2.607E-09	1.161E-06	1.070E+02	2.220E-02
STOMACH	1.856E-08	6.695E-08	6.459E+01	1.335E-02
BOWEL	5.380E-08	3.030E-08	3.197E+01	6.650E-03
LIVER	6.695E-09	8.413E-08	7.055E+01	1.466E-02
PANCREAS	6.313E-09	6.882E-08	4.235E+01	8.797E-03
URINARY	3.405E-09	1.443E-08	2.632E+01	5.478E-03
OTHER	7.722E-09	8.418E-08	5.180E+01	1.076E-02

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* NUCLIDE C-11 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	7.396E-09	2.501E-09	5.957E+09	1.232E+06
BREAST	6.822E-09	4.371E-09	5.550E+09	1.140E+06
R MAR	6.226E-09	4.153E-09	4.551E+09	9.398E+05
LUNGS	7.342E-09	1.882E-07	4.440E+09	9.176E+05
THYROID	3.169E-09	3.860E-09	5.550E+09	1.140E+06
ENDOST	3.850E-09	3.150E-09	5.217E+09	1.073E+06
RMNDR	1.684E-07	1.949E-08	4.447E+09	9.161E+05
EFFEC	5.522E-08	3.042E-08	5.058E+09	1.043E+06

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	1.972E-09	1.315E-09	1.441E+03	2.977E-01
BONE	6.814E-11	5.575E-11	9.233E+01	1.899E-02
THYROID	1.441E-10	1.756E-10	2.524E+02	5.183E-02
BREAST	2.672E-09	1.712E-09	2.174E+03	4.464E-01
LUNG	3.640E-09	9.723E-08	2.201E+03	4.549E-01
STOMACH	2.183E-07	2.121E-08	1.335E+03	2.743E-01
BOWEL	4.641E-09	6.497E-10	6.594E+02	1.357E-01
LIVER	2.981E-09	2.129E-09	1.453E+03	2.996E-01
PANCREAS	1.136E-08	2.463E-09	8.734E+02	1.801E-01
URINARY	1.536E-09	5.707E-10	5.432E+02	1.119E-01
OTHER	1.389E-08	3.012E-09	1.068E+03	2.203E-01

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* NUCLIDE N-13 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	2.884E-09	9.321E-10	5.994E+09	1.232E+06
BREAST	2.974E-09	2.003E-09	5.550E+09	1.140E+06
R MAR	2.594E-09	1.895E-09	4.551E+09	9.398E+05
LUNGS	3.402E-09	1.334E-07	4.440E+09	9.176E+05
THYROID	9.159E-10	1.765E-09	5.550E+09	1.140E+06
ENDOST	1.538E-09	1.476E-09	5.217E+09	1.073E+06
RMNDR	1.139E-07	9.503E-09	4.447E+09	9.161E+05
EFFEC	3.612E-08	1.972E-08	5.067E+09	1.043E+06

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	8.215E-10	6.003E-10	1.441E+03	2.977E-01
BONE	2.723E-11	2.613E-11	9.233E+01	1.899E-02
THYROID	4.166E-11	8.026E-11	2.524E+02	5.183E-02
BREAST	1.165E-09	7.845E-10	2.174E+03	4.464E-01
LUNG	1.687E-09	5.959E-08	2.201E+03	4.549E-01
STOMACH	1.559E-07	1.057E-08	1.335E+03	2.743E-01
BOWEL	2.204E-09	2.365E-10	6.596E+02	1.359E-01
LIVER	1.382E-09	1.037E-09	1.453E+03	2.996E-01
PANCREAS	6.420E-09	1.148E-09	8.734E+02	1.801E-01
URINARY	7.524E-10	2.494E-10	5.432E+02	1.119E-01
OTHER	7.852E-09	1.404E-09	1.068E+03	2.203E-01

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* NUCLIDE O-15 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	3.156E-10	8.741E-11	5.994E+09	1.232E+06
BREAST	5.258E-10	3.509E-10	5.550E+09	1.143E+06
R MAR	4.135E-10	3.306E-10	4.551E+09	9.398E+05
LUNGS	6.663E-10	4.839E-08	4.440E+09	9.176E+05
THYROID	6.929E-11	3.141E-10	5.550E+09	1.140E+06
ENDOST	2.338E-10	2.633E-10	5.217E+09	1.073E+06
RMNDR	3.594E-08	1.270E-09	4.447E+09	9.161E+05
EFFEC	1.108E-08	6.319E-09	5.067E+09	1.044E+06

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	1.310E-10	1.047E-10	1.441E+03	2.977E-01
BONE	4.138E-12	4.660E-12	9.233E+01	1.899E-02
THYROID	3.152E-12	1.429E-11	2.524E+02	5.183E-02
BREAST	2.060E-10	1.374E-10	2.174E+03	4.478E-01
LUNG	3.304E-10	1.770E-08	2.201E+03	4.549E-01
STOMACH	5.324E-08	1.161E-09	1.335E+03	2.743E-01
BOWEL	2.960E-10	1.884E-11	6.597E+02	1.359E-01
LIVER	2.628E-10	2.029E-10	1.453E+03	2.996E-01
PANCREAS	1.498E-09	1.878E-10	8.743E+02	1.801E-01
URINARY	1.507E-10	3.804E-11	5.432E+02	1.119E-01
OTHER	1.833E-09	2.297E-10	1.069E+03	2.203E-01

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* NUCLIDE AR-41 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	0.000E+00	2.946E-10	7.733E+09	1.347E+06
BREAST	0.000E+00	3.236E-10	6.956E+09	1.210E+06
R MAR	0.000E+00	3.083E-10	5.957E+09	1.032E+06
LUNGS	0.000E+00	3.443E-09	5.883E+09	1.025E+06
THYROID	0.000E+00	3.465E-10	7.326E+09	1.276E+06
ENDOST	0.000E+00	2.551E-10	6.290E+09	1.095E+06
RMNDR	0.000E+00	3.532E-10	5.964E+09	1.037E+06
EFFEC	0.000E+00	6.964E-10	6.595E+09	1.147E+06

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	0.000E+00	9.766E-11	1.887E+03	3.270E-01
BONE	0.000E+00	4.515E-12	1.113E+02	1.938E-02
THYROID	0.000E+00	1.576E-11	3.332E+02	5.806E-02
BREAST	0.000E+00	1.268E-10	2.725E+03	4.739E-01
LUNG	0.000E+00	2.721E-09	2.917E+03	5.081E-01
STOMACH	0.000E+00	8.832E-11	1.768E+03	3.079E-01
BOWEL	0.000E+00	2.937E-11	8.983E+02	1.562E-01
LIVER	0.000E+00	1.208E-10	1.946E+03	3.398E-01
PANCREAS	0.000E+00	8.577E-11	1.177E+03	2.054E-01
URINARY	0.000E+00	4.233E-11	7.381E+02	1.281E-01
OTHER	0.000E+00	1.049E-10	1.439E+03	2.513E-01

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* NUCLIDE BR-84 *
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DOSE RATE CONVERSION FACTORS

Organ	Ingestion	Air Inhalation	Ground Immersion	Surface
GONADS	0.000E+00	0.000E+00	1.188E+10	1.850E+06
BREAST	0.000E+00	0.000E+00	1.088E+10	1.687E+06
R MAR	0.000E+00	0.000E+00	9.287E+09	1.443E+06
LUNGS	0.000E+00	0.000E+00	9.065E+09	1.410E+06
THYROID	0.000E+00	0.000E+00	1.095E+10	1.709E+06
ENDOST	0.000E+00	0.000E+00	9.583E+09	1.498E+06
RMNDR	0.000E+00	0.000E+00	9.206E+09	1.430E+06
EFFEC	0.000E+00	0.000E+00	1.018E+10	1.583E+06

RISK CONVERSION FACTORS

Cancer	Ingestion	Air Inhalation	Ground Immersion	Surface
LEUKEMIA	0.000E+00	0.000E+00	2.941E+03	4.570E-01
BONE	0.000E+00	0.000E+00	1.696E+02	2.652E-02
THYROID	0.000E+00	0.000E+00	4.982E+02	7.775E-02
BREAST	0.000E+00	0.000E+00	4.261E+03	6.609E-01
LUNG	0.000E+00	0.000E+00	4.494E+03	6.989E-01
STOMACH	0.000E+00	0.000E+00	2.779E+03	4.306E-01
BOWEL	0.000E+00	0.000E+00	1.403E+03	2.175E-01
LIVER	0.000E+00	0.000E+00	3.035E+03	4.708E-01
PANCREAS	0.000E+00	0.000E+00	1.855E+03	2.869E-01
URINARY	0.000E+00	0.000E+00	1.161E+03	1.801E-01
OTHER	0.000E+00	0.000E+00	2.269E+03	3.509E-01