NUREG/CR-0315
BNL-NUREG-50882

Environmental Radioiodine Monitoring to Control Exposure Expected From Containment Release Accidents

Final Report

Prepared by C. Distenfeld, J. Klemish

Brookhaven National Laboratory

Prepared for
U. S. Nuclear Regulatory Commission

Available from

National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-0315
BNL-NUREG-50882
RE

Environmental Radioiodine Monitoring to Control Exposure Expected From Containment Releases Accidents

Final Report

Manuscript Completed: November 1978
Date Published: December 1978

Prepared by
C. Distenfeld, J. Klemish

Safety and Environmental Protection Division
Brookhaven National Laboratory
Upton, NY 11973

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. A3056-8
Under Contract No. EY-76-C-02-0016

1322 239

Environmental Radioiodine Monitoring to Control Exposure Expected from Containment Release Accidents

C. Distenfeld and J. Klemish

Abstract

Reactor accidents may cause releases of radionuclides from containment. The active mater..al would cause exposure to man through inhalation of gases or aerosols or through consumption of food products containing deposited radioactive particles.

Certain aspects of internal exposure are considered. They are field assessment of the exposure potential of milk, and predictions of human thyroid dose commitment based on direct measurements of radioiodine incorporated within the human thyroid.

Radioiodine in milk may be inferred by measurements of radioiodine in cow thyroids, and by measuring deposited radioiodine on pasture grasses consumed by cows. Direct radioiodine measurements on milk were also considered.

Human thyroid exposure could be through inhalation as well as ingestion. Predictions of thyroid dose commitment can be based on measured human thyroid radioiodine content and known metabolic parameters.

The report is organized in the order of their introduction above starting with inferred milk radioiodine content based on measurement of radioiodine in the cow thyroid.

Acknowledgments

The bovine metabolic calculations were performed on a CDC 6000 computer using the National Institute of Health's program SAAM. Dr. Rita Straub, a member of the BNL Medical Department, carefully guided our efforts toward successful calculations.

Dose commitment calculations, made on the basis of thyroid uptake measurements, are effected by several time dependent functions. Mr. Alan Kuehner was instrumental in composing the system of equations that describe the problem, and in computer solutions.

The value of any report can be enhanced by a careful critical review. Dr. John Baum considered the work technically and editorially, and his suggestions are reflected in the final document.

Summary

Reactor accidents may cause releases of radionuclides from containment. The active material would cause exposure to man through inhalation of gases or aerosols or through consumption of food products containing deposited radioactive particles.

Certain aspects of internal exposure are considered. They are field assessment of the exposure potential of milk, and predictions of human thyroid dose commitment based on direct measurements of radioiodine incorporated within the adult human thyroid.

Radioiodine in milk is inferred by measurements of radioiodine in cow thyroids, and by measuring deposited radioiodine on pasture grasses consumed by cows. Direct radioiodine measurements on milk are also considered.

Inhalation is an alternate pathway to thyroid exposure. Predictions of thyroid dose commitment are based on measured human thyroid radioiodine content and known metabolic parameters.

The report is organized in the order of introduction starting with inferred milk radioiodine content based on measurement of radioiodine in the cow thyroid.

TABLE OF CONTENTS

1322 242

LIST OF FIGURES

Figure

LIST OF TABLES

Table

1322 244

1. PREDICTIONS OF RADIOIODINE IN MILK BASED ON COW THYROID MEASUREMENTS

1.1 Introduction

Minimizing ingestion depends on control of supplied milk. Radioiodine content governs whether milk can be accepted for general use, home consumption, delayed by diversion to cheese or dried milk, or be rejected. Radioactive content can be measured at farms, dairy collecting points or markets.

Farm measurements permit control of smaller milk stocks, reducing the possibilities of contaminating larger dairy pools. Field determinations can involve direct pasture measurements. Extensive research allows prediction of radioiodine in milk based on direct measurement of radioiodine on pasture grasses. When feeding primarily stored hay, grain or processed feed, an alternate measurement system is required. Radioiodine intake is then only possible by respiration of aerosols and gases and not by consumption of pasturage.

Direct measurements on cow thyroids can be used to predict milk radioiodine content. Simple, external, under neck measurements can be used to predict radioiodine content in the milk. Measurement time can be less than a minute per animal. Representative herd determinations are possible in 5 to 10 minutes for an average collected herd of ∿100 cows, assuming 10 cows are representative.

1.2 Bovine Iodine Metabolism

Prediction of radioiodine concentrations in milk depends on iodine metabolism. Two models were considered, the first, developed by Dr. J.K. Miller,(1) is designated the eastern model, and the second by Dr. C. Blincoe(2) is designated the western model. Each model represents iodine metabolism somewhat differently and with different rate constants. The eastern and western models and rate constants are outlined in Figures 1.1 and 1.2. Time dependent calculations were made for both models for both single and continuous feeding. Twice daily milking was assumed with 80% discharge for all milkings. Eastern model results, shown in Figure 1.3, indicated that thyroid uptake of iodine reached a maximum of 12.5% three days after a single intake. After 7.5 days of ingestion, iodine accumulated in milk and excreta reached levels of 9 and 80% respectively.

The western model provided very similar results for iodine transport in milk and excreta. The most striking difference between the two models was the magnitude of iodine uptake by the thyroid. The western study, Figure 1.4, predicted a maximum thyroid uptake of about 41% of intake, about three times larger than the eastern model. Regional differences in stable dietary iodine supplements[3] and feed could be responsible. Part of the data base for the eastern model included cows given a standard commercial concentrated feed containing iodized salt. Some degree of iodine blocking was likely[4]. Extensive use of supplementary stable iodine may be related to the goitrogenic[5] nature of corn silage-soybean oil meal feed that was widely used.

The eastern model was adopted to provide some regional conservatism for predicting general milk radioiodine content from thyroid uptake.

1.3 Measurement of Radioiodine in the Cow Thyroid

Practical predictions of milk-radioiodine content depend on direct measurement of thyroid radioiodine and the time dependent metabolic relationship between thyroid uptake and milk release of iodine. Radioiodine assay of cow thyroid uptake can be made with CDV700 civil defense instruments fitted with standard D-103 GM probes or with specially filtered Victoreen 6306 GM detectors.

The relationship between instrument counts per minute, CPM, and microcuries of ^{131}I in the cow thyroid was measured with an appropriate cow thyroid phantom. A full scale model of a bovine neck section[6] was constructed containing a trachea and two flattened triangular thyroid lobes, laterally arranged (see Figure 1.5). The hollow thyroid lobes were filled with a total of 37.5 cm^3 [1] of radioiodine solution. The neck section was filled with water immersing the model thyroid lobes but leaving the model trachea dry.

1.4 Results

Measurements were made with probes arranged (a) longitudinally below the model trachea and centered between the model lobes, and (b) laterally orientated and centered. Results for various detectors are summarized in Table 1.1.

Slightly higher counting rates per unit activity were observed with longitudinal orientation. However, ease of lateral probe positioning probably makes this the preferred method.

Proper probe position for optimum detection of thyroid radioiodine uptake can be determined by palpation[6]. Placing one's fingers at the throat-neck juncture (Figure 1.6) and locate a lateral subsurface indentation corresponding to the arch of cricoid cartilage (see Figure 1.7). The probe should be placed to the rear of the arch, adjacent to the position of the Isthmus of thyroid.

1322 246

The measured counting rate can be converted to thyroid uptake by use of Table 1.1. Iodine metabolism provides the relationship between thyroid uptake and radioiodine in milk.

Two feeding scenarios are considered. Continuous feeding represents maximum intake and transfer to milk, while single feeding results in smaller values. Single feeding results from dairy farmers switching their herds to stored feed to limit exposure or cattle inhaling radioiodine from a passing cloud while on stored feed.

The predicted cow thyroid net counting rate for milk containing 8.7 nanocuries per liter is shown in Figures 1.8 and 1.9 for a 6306 probe and for single and continuous feeding. The family of curves labeled "Hours After Reactor Shutdown", allow adjustment for changing iodine isotope composition with time. The curves can be used by selecting a time after start of feeding along the abscissa. Follow a vertical line to the intersection or interpolation of time after reactor shutdown, and the corresponding thyroid net CPM is on the ordinate for a milk ^{131}I activity of 8.7 nCi/ℓ. This value corresponds to $\sim$1 rad dose commitment to a 2 gm thyroid for daily milk consumption of one liter.

1.5 Discussion and Results

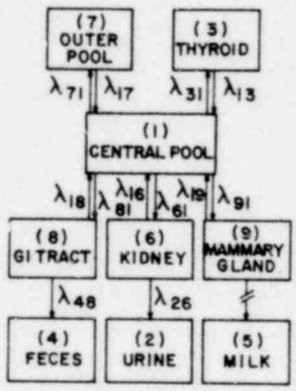
Two uncertainties were perceived and were difficult to quantify. They were regional variability in location and size of the bovine thyroid gland and in bovine iodine metabolism. Good agreement between the two models was apparent for the fraction of iodine intake that later appeared in the milk. However, the two models differed by a factor of three in bovine thyroid uptake. This would lead to similar uncertainties in predicting radioiodine in milk from thyroid measurements.

Sensitivity of the method was based on an initial ^{131}I milk concentration of 8.7 nCi/ℓ . Continuing intake corresponds to a projected dose commitment of about 1 rem to a 2 gm thyroid. This sensitivity can be achieved at the farm two days after reactor shutdown for continuous feeding and one day for single feeding, assuming normal 6306 probe background values.

1322 247

Table 1.1 ^{131}I Calibration of Various Detectors with a Cow Thyroid Phantom

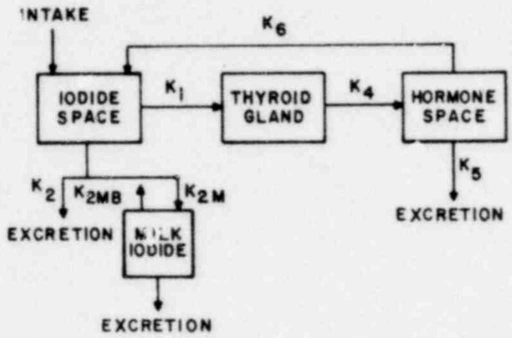
Detector[16]		Longitudinal Net CPM/μCi	Lateral Net CPM/μCi
OCD-D-103	Probe	9.8±2%	9.2±9%
TGM	Probe	54.6±1%	51.8±5%
6306	Probe	110±7%	105±5%



	Compartments and direction	λ (per hour)	SE (per hour)
λ_{61}	Central pool to kidney	1.80	.07
λ_{16}	Kidney to central	1.57	.05
λ_{31}	Central pool to thyroid	.0258	.0013
λ_{13}	Thyroid to central pool	.00502	.00091
λ_{71}	Central pool to outer pool	$.837 + .172\lambda_{61}$	-
λ_{17}	Outer pool to central pool	.645	.066
λ_{91}	Central pool to mammary gland	.173	.003
λ_{19}	Mammary gland to central pool	$-.576 + 8.074\lambda_{91}$	-
λ_{81}	Central pool to GI tract	.145	.039
λ_{18}	GI tract to central pool	.068	.016
λ_{26}	Kidney to urine	$.14515 - .05126\lambda_{61}$	-
λ_{48}	GI tract to feces	.0321	.0077

Figure 1.1 Eastern Metabolic Model and Rate Constants

1322 248



Parameter	Value, hr^{-1}
k_1	.026
k_2	.023
k_4	.0026
k_5	.010
k_6	.020
k_{2m}	.0064
k_{2mb}	.0045

Figure 1.2 Western Metabolic Model and Rate Constants

1322 249

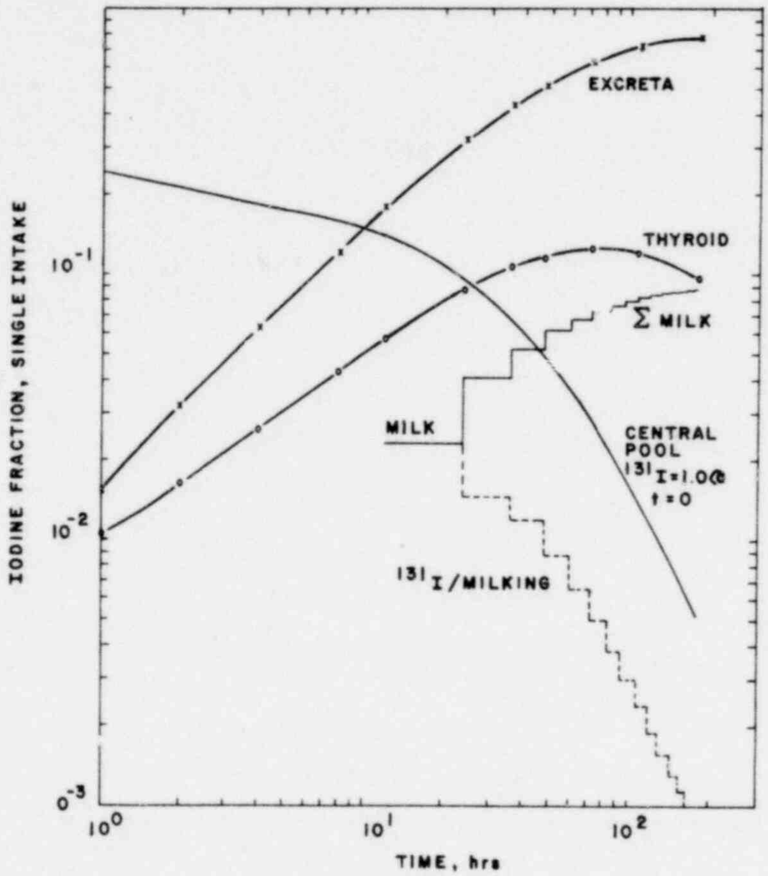


Figure 1.3 Eastern Cow Iodine Metabolism

1322 250

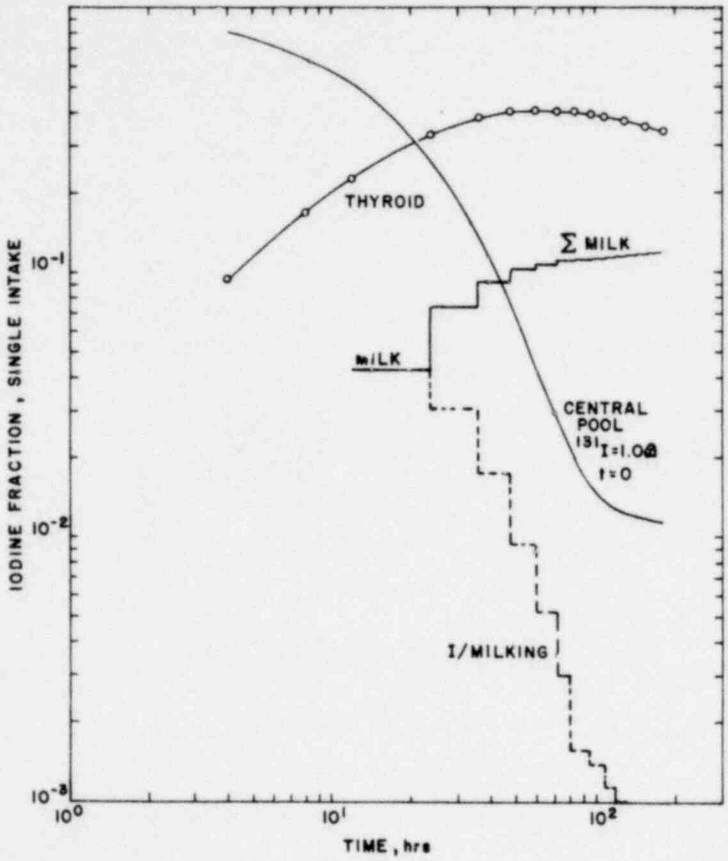


Figure 1.4 Western Cow Iodine Metabolism

1322 251

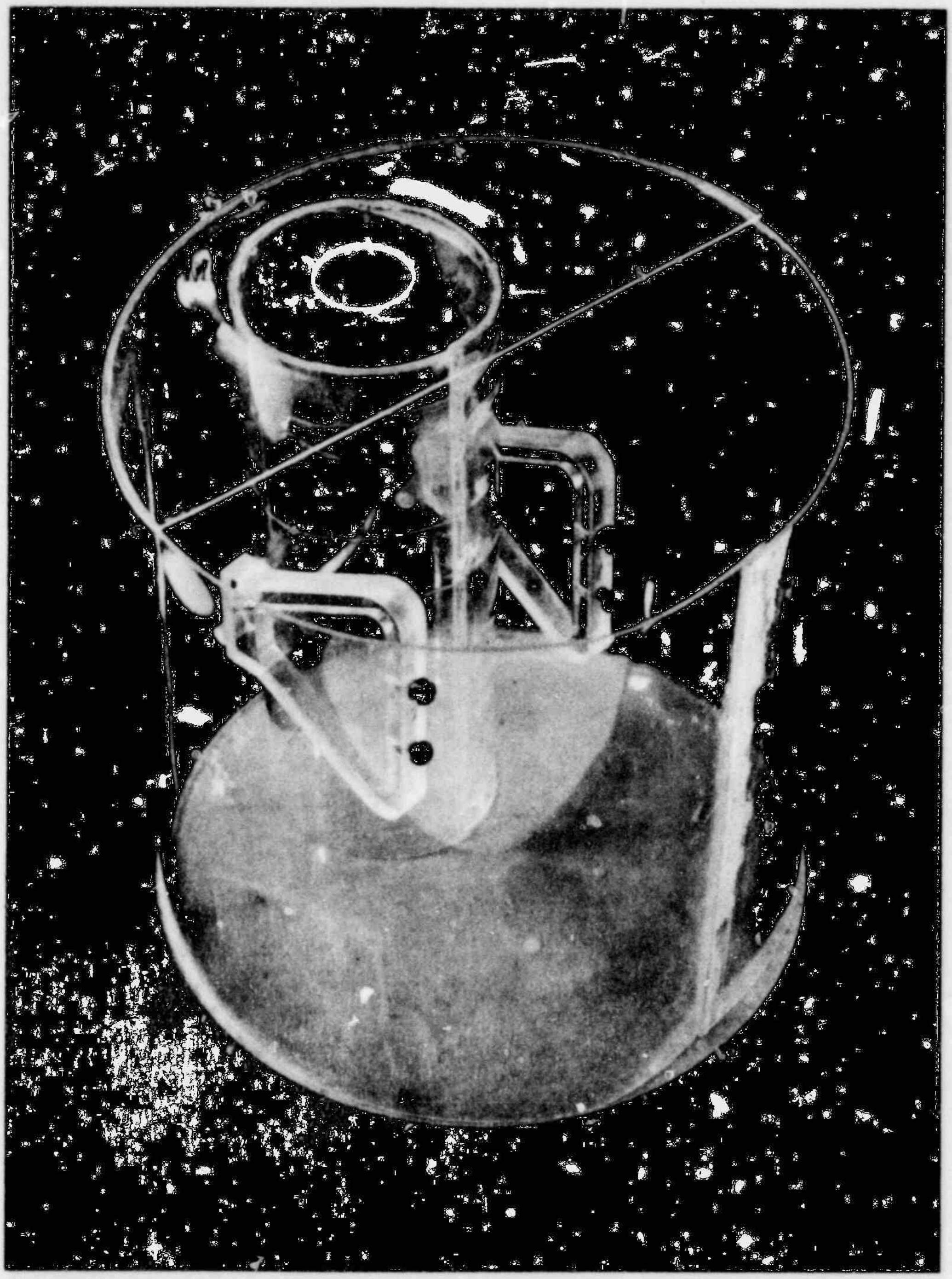


Figure 1.5 Cow Thyroid Phantom

1322 252

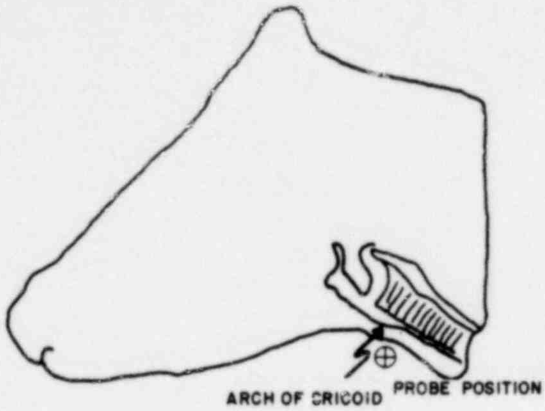


Figure 1.6 Cow Silhouette with Trachea

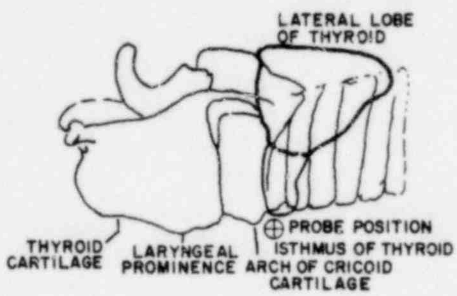


Figure 1.7 Cow Trachea with Thyroid

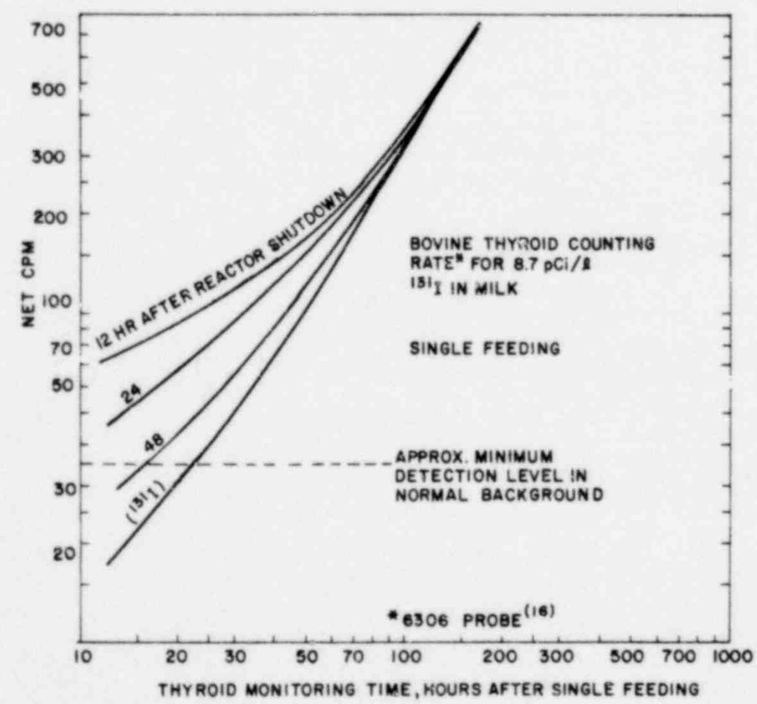


Figure 1.8 Cow Thyroid Counting Rate with a 6306 Probe for 8.7 nCi/ℓ ^{131}I in Milk After Single Feeding

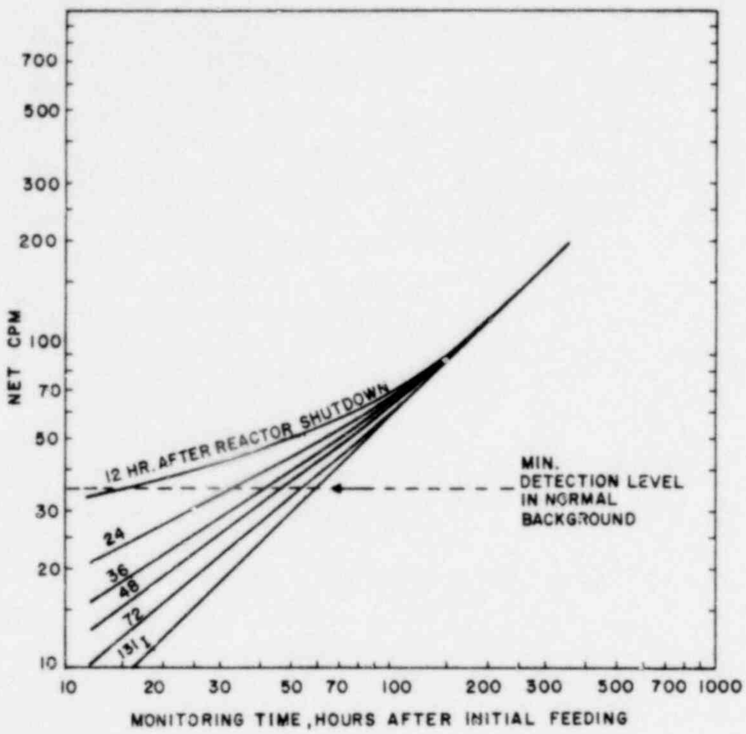


Figure 1.9 Cow Thyroid Counting Rate with a 6306 Probe for 8.7 nCi/ℓ in Milk for Continuous Feeding

1322 254

2. MILK RADIOIODINE CONTAMINATION FROM GROUND DEPOSITED FISSION PRODUCTS

2.1 Introduction

Radioiodine contaminated pasturage consumed by dairy cattle results in radioiodine in milk. The magnitude of the radioiodine concentration in milk will be proportional to the amount of contamination. Thus, pasture measurements can be used to predict radioiodine concentration in milk.

The pasture contamination - measurement relationship was studied experimentally and extrapolated to field depositions expected from BWR and PWR release from containment accidents. A 20 meter diameter pseudo fallout field having .144 mCi/m^2 was constructed, using 84 ^{131}I sources. The field was used to calibrate a number of instruments. Corrections were calculated to adjust the instrument calibrations from a 20 meter diameter to the more appropriate infinite field case.

Fallout deposits contain a mixture of radionuclides, which varies in composition and depends on the type of accident and reactor. Previous calculations of time dependent ratios of radioiodine to total non-gaseous fission products were used to correct the ^{131}I infinite field calibrations for total fallout.

2.2 Field Calibration and Extrapolation to an Infinite Field

Previous calculations[(7)] were used to design an adequate calibration range. The range consisted of a 20 meter diameter pasture like area on which were placed small point sources of ^{131}I. Eighty-four small plastic petri dishes of 15cc volume were used as source containers. Five cc of activated charcoal followed by filter paper were placed in the bottom of the petri dishes. Radioiodine solution was dispensed onto the filter paper. Taped, plastic petri dish covers were used to seal the sources.

An adjustable volume Oxford[(8)] dispenser was used to provide reproducible 0.2cc aliquots of ^{131}I in 1/10 normal sodium hydroxide solution.

Twenty sources were loaded with 0.17 mCi and 64 sources with 0.65 mCi. The sources were measured with an ion chamber to verify uniform loading. The few sources showing ~10% deviation from the mean were placed near the outside diameter of the calibration range. The resulting calibration range had an average deposition of .144 mCi/m^2.

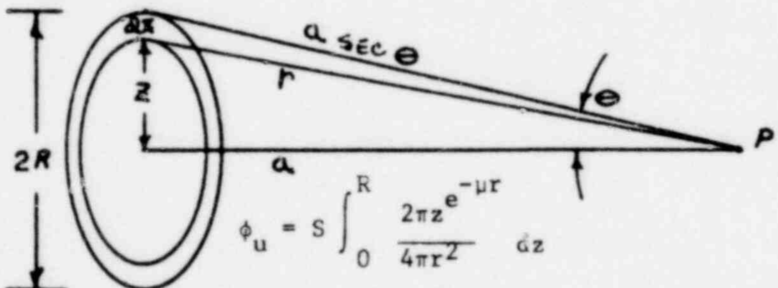
1322 255

The center of the calibration range was organized into a cross like structure with 20 sources about 1.07 meters apart. The remaining sources, of 4 times the activity, were placed on a 2.14 meter grid shown diagramatically in Figure 2.1 and pictorially in Figure 2.2. Grid locations were marked with anchored white plastic coated paper cup lids; so that the sources could be dispensed rapidly and reproducibly.

A water filled whole body phantom was placed in the center of the field to provide realistic radiation shadowing. Standard probe monitoring positions were approximated for both a hand held probe extended ∿18" and a probe retained in a CDV 700 handle mount adjacent to the torso.

Calibration data error was controlled to less than ±5% standard deviation of the mean by use of electronic scalers located in a trailer shown in the foreground of Figure 2.2. Results for ^{131}I are shown on Table 2.1 in terms of Net CPS per mCi/m^2 and per mR/hr for the 20 meter diameter calibration pasture, and for different probes, and instruments. Infinite field results were obtained by correcting the 20 meter diameter data by a calculated dose rate ratio of infinite field to 20 meter diameter field.

For uniformly deposited disc sources, the uncollided γ fluence at point p for source S of γ/cm^2sec, and linear absorption length μ is:



$$\phi_u = S \int_0^R \frac{2\pi z e^{-\mu r}}{4\pi r^2} dz$$

since $Z^2 = r^2 - a^2$ $\quad zdz = rdr$

$$\phi_u = \frac{S}{2} \int_0^R \frac{e^{-\mu r}}{r^2} rdr$$

Adopting the Goldstein(9) form of dose buildup factor for point sources where $K \equiv \frac{\mu}{\mu_a} - 1 = 2.3$ for 365 keV γ's produced

1322 256

by the decay of ^{131}I, $Bp(\mu r) = 1 + k\mu r$

The buildup fluence is

$$\phi_b = \frac{S}{2}\int_{o}^{R} (1 + k\mu r)\,\frac{e^{-\mu r}}{r}\,dr$$

Let $\mu r = t$; Note: $r = a$ at $R = o$ lower limit

$\therefore\ r = t/\mu$; $dr = dt/\mu$

$$\phi_b = \frac{S}{2}\left[\int_{\mu a}^{\mu a \sec\theta} \frac{e^{-t}}{t/\mu}\,dt/\mu + \int_{\mu a}^{\mu a \sec\theta} ke^{-t}dt\right]$$

$$\phi_b = \frac{S}{2}\left[(E_1(\mu a) - E_1(\mu a \sec\theta) + k(e^{-\mu a} - e^{\mu a \sec\theta})\right]$$

where $E_1(t) \equiv -.57722 - \log t + t + \frac{t^2}{2L2} + \frac{t^3}{3L3} + \ldots$

Since $\dot{X}\ \alpha\phi\cdot E\cdot\mu/a^{air}$ where $\dot{X} \equiv$ dose rate in Roentgens/time

Assume E(uncollided) = E(buildup) and $\mu a = .0129$ for 100 cm above the ground

$$\frac{\dot{X}(10M)}{\dot{X}_\infty} = \frac{\phi_b(10M)}{\phi_{b\infty}} = \frac{2.56}{6.04} = .42$$

A slightly different approach was taken by Haynes[7]. He divided the infinite field calculation into regions above and below $\mu a \sec\theta = 1$. For the smaller region closer to the source, he used the method outlined above. The buildup function for this other region was changed to the more accurate Berger[9] form.

$$B_p = 1 + L\mu r e^{-\beta\mu r}$$

Parameters L and β were obtained by interpolating the dose buildup factors of Goldstein and Wilkins[10] for water, for 365 KeV, and for $\mu r = 1$ and 2. Hayne's results indicate the infinite field correction factor was, 1/.406, in good agreement with the derived value of 1/.42.

The calibration data were corrected by 1/.406 in preference to the Berger form of buildup function for absorption lengths $>\mu r = 1$.

2.3 Radioiodine Pasture to Milk Pathway

WASH 1400[11] related to radioiodine consumed by dairy animals to milk contamination. They assume an average cow consumes

11.8 kg/day of pasturage and obtains this quantity by grazing 45 m^2 with 50% of the iodine deposited on the grasses.

Lengemann[12] empirically determined the radioiodine fraction, A, of daily intake that appears in milk as a function of time t in days.

$$A = .0091e^{.021t}\left[1-e^{-.292t}\right] \text{liter}^{-1}$$

Radioiodine pasture levels decline by radioactive decay and weathering. In WASH 1400, a weathering half-life of 14 days was assumed. Thus, the weathering factor, L, is $e^{-.0495t}$. Finally, ^{131}I decays with an 8.06 day half-life leading to the radioactive decay factor $e^{-.086t}$. Therefore, the radioiodine milk concentration, Q, in mCi/ℓ for a field deposition of C mCi/m^2 is

$$Q = C \times 45 \times .5 \times A \times L \times R$$

The expression was evaluated for a milk concentration of 8.7 nCi/ℓ for decay times of 1,2,4 and 8 days. Results are shown in Table 2.2. It is interesting to note for a fixed milk concentration for times varying from 1 to 8 days after shutdown, the initial iodine deposition is roughly constant. Iodine released to milk increases with time for continuing feeding. This tends to compensate for weathering and decay, reducing the expected time dependence for the first 8 days.

Radioactive deposition from a release from containment accident contains a mixture of fission products. The effect of the mixture on instrument response was calculated[13] earlier. The calculations provided time dependent ratios of iodine instrument response to total non-gaseous fission products for the 9 PWR and 5 BWR WASH 1400 hypothetical accident cases. A constant deposition velocity was assumed for all of the non-gaseous fission products. The earlier ratios were corrected for the calculated instrument response due to the total fission iodine compared to ^{131}I. Finally, the corrected ratios and the ^{131}I $field_{\infty}$ calibrations were used to predict the Victoreen probe instrument responses one meter above an infinite field contaminated with mixed fission products. Predictions were made for 1,2 and 4 days after reactor shutdown and for a pasture that would produce milk containing 8.7 nCi/ℓ ^{131}I. Results are shown on Table 2.3 and indicate that the hypothetical BWR accident cases produce about twice the instrument response of the PWR's for a given concentration of radioiodine in milk. This is due to the larger fraction of iodine trapped in a PWR containment and therefore not available for release. BWR 5 was treated as a special case since the release composition and accident scenario were not characteristic of the other BWR's. In this case, a large pipe break without core melt down and without use of the pressure suppression pool was assumed. Cladding failure and release of the gap activity to the containment were assumed. It was also assumed that the release was ultimately filtered and discharged by an elevated stack. Except for the magnitude of noble gas release, the non-gases components may experience roughly the same conditions as the PWR cases. Instrument predictions for a BWR 5 accident class closely match the PWR cases which follows this contention.

The data are graphically displayed on Figure 2.3. Normal background values for filtered Victoreen 6306 probes are less than 1 cps. Thus, the lower detectable milk concentrations would be less than 1 nCi/ℓ of ^{131}I.

2.4 Summary

A 20 meter diameter ^{131}I calibration field was constructed to approximate uniform contamination. Calculations were made to correct the results to an infinite field. Earlier calculations were adopted to account for the contributions expected from other fission products for the WASH 1400 PWR and BWR hypothetical accident cases. The calculations were used to predict 6306 probe responses to pastures producing milk containing 8.7 nCi/ℓ ^{131}I that were contaminated by mixed fission products from PWR and BWR accidents. The method can easily be used to evaluate pastures capable of producing milk of less than 1 nCi/ℓ of ^{131}I.

1322 259

Table 2.1 Detector Response to Ground Deposited ^{131}I

Instrument	BKG CPM	Probe Hand Held: 10 Meter Radius Net CPS/mR/hr	Probe Hand Held: 10 Meter Radius Net CPS/mCi/m^2	Probe Hand Held: ∞ Field Net CPS/mCi/m^2	Probe on Instrument: 10 Meter Radius Net CPS/mR/hr	Probe on Instrument: 10 Meter Radius Net CPS/mCi/m^2	Probe on Instrument: ∞ Field Net CPS/mCi/m^2	^{137}Cs Calib Net CPS/mR/m
[1]OCD-D-103-1	13±9%	7.9±5%	21.8±5%	54	6.7±3.5%	18.6±3.5%	46	9.3± 2%
OCD-D-103-2	18±7%	8.0±2%	22.1±5%	54	7.0±6%	19.3±6%	47	9.5± 2%
[2]V 1	45±5%	95±3%	265±3%	652	84±4%	232±4%	571	76± 1%
V 2	48±5%	108±2%	298±2%	734	89±2%	247±2%	610 } 599±4%	82± 1%
V 3	47±5%	100±3%	276±3%	680	86±5%	240±5%	590	78± 1%
V 4	49±5%	105±2%	292±2%	719	92±4%	255±4%	628	80± 1%
[3]TGM-1	19±7%	43±4%	120±4%	296	38±2%	105±2%	259	34± 1%
TGM-2	20±7%	45±2%	124±2%	304	38±2%	106±2%	261	34± 1%
[4]Ludlum	192±3%	565±2%	1566	3857				235±.5%

Note: [1]Std OCD-D-103 GM tubes in std CDV shield

[2]Victoreen 6306 GM tube in 1.27 mm Pb +0.8 mm Cu shield

[3]NP358 special 3.875 inches LOA by TGM Detectors Inc. shielded as 2 above

[4]Ludlum model 44-3 Low Energy Gamma Scintillator with companion instr.

Table 2.2 ^{131}I Pasture Contamination to Produce a Q of 8.7 nCi/ℓ in Milk

Time days	A x10^3	L	R	(mCi/m^2) ^{131}I
1	2.4	.95	.92	.19
2	4.2	.91	.84	.12
4	6.8	.86	.77	.09
8	9.7	.67	.50	.12

1322 261

Table 2.3 6306 Probe[16] Response to Pastures Contaminated by PWR and BWR Accidents Normalized to Resulting Milk ^{131}I levels of 8.7 nCi/ℓ

Time	^{131}I on Pasture	Instr	$\Sigma I/^{131}I$	PWR		BWR			
				PWR1-9	Intr.	BWR1-4	Intr.	BWR5	Intr.
days	mCi/M	$\frac{CPS(^{131}I)}{8.7\ nCi/\ell}$		ΣFis.P/ΣI	$\frac{CPS(PWR)}{8.7\ nCi/\ell}$	ΣFis.P/ΣI	$\frac{CPS(BWR1-4)}{8.7\ nCi/\ell}$	ΣFis.P/ΣI	$\frac{CPS(BWR5)}{8.7\ nCi/\ell}$
1	.19	113	2.70	1.96	596	4.0	1216	1.49	453
2	.12	72	1.69	2.33	283	4.5	553	1.69	206
4	.09	51	1.16	2.70	159	5.88	347	2.0	118

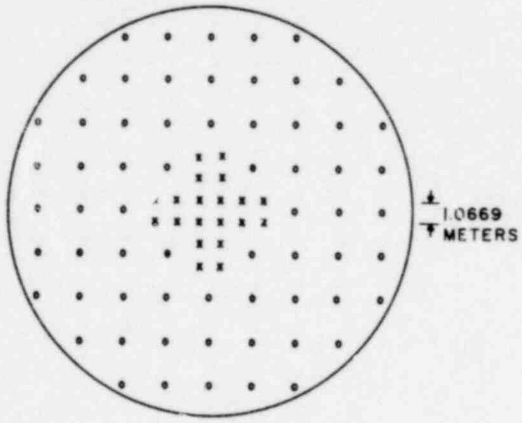


Figure 2.1 Simulated ^{131}I Semi-Infinite Fallout Field

1322 263

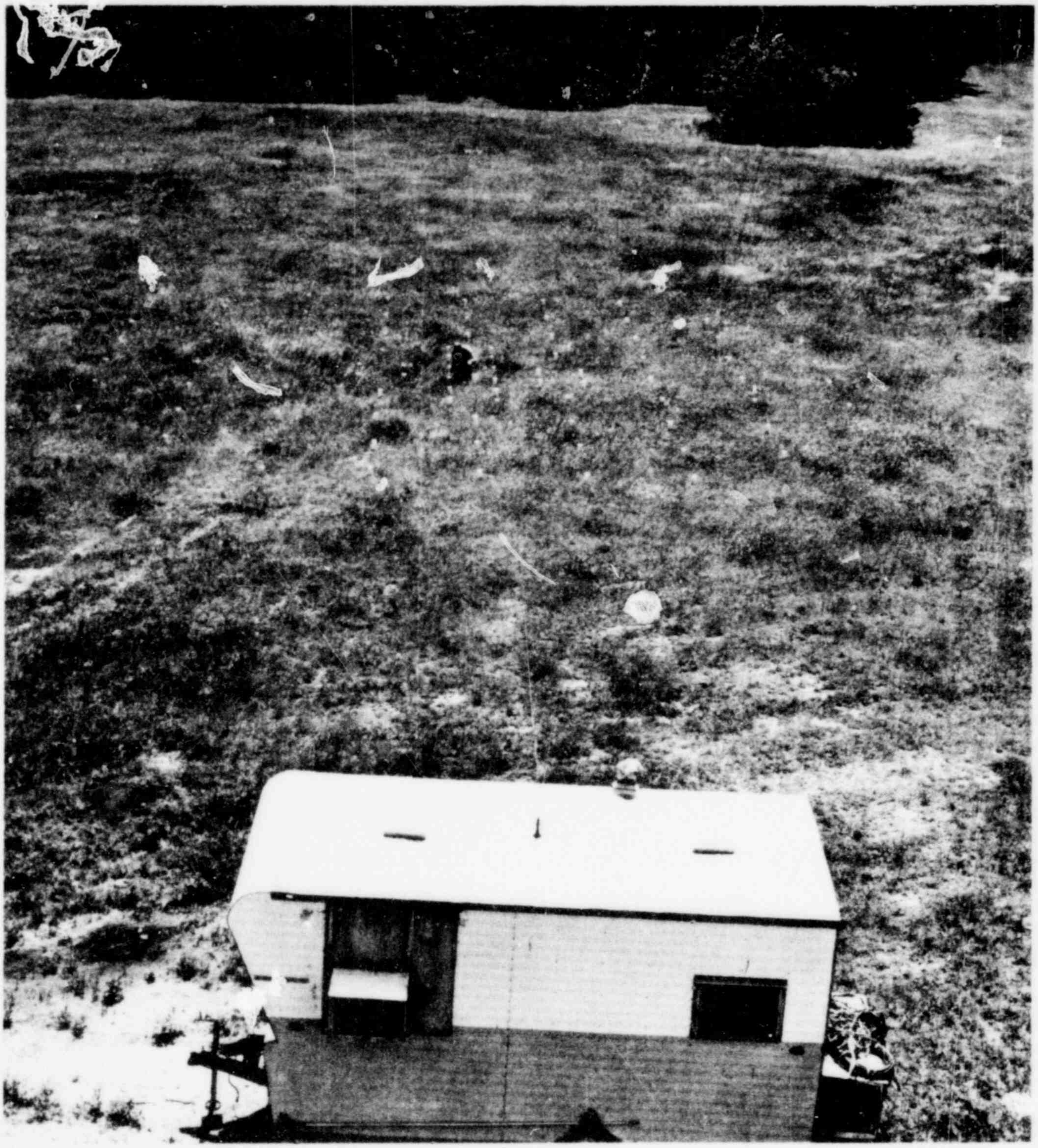


Figure 2.2 Simulated ^{131}I Semi-Infinite Fallout Field

1322 264

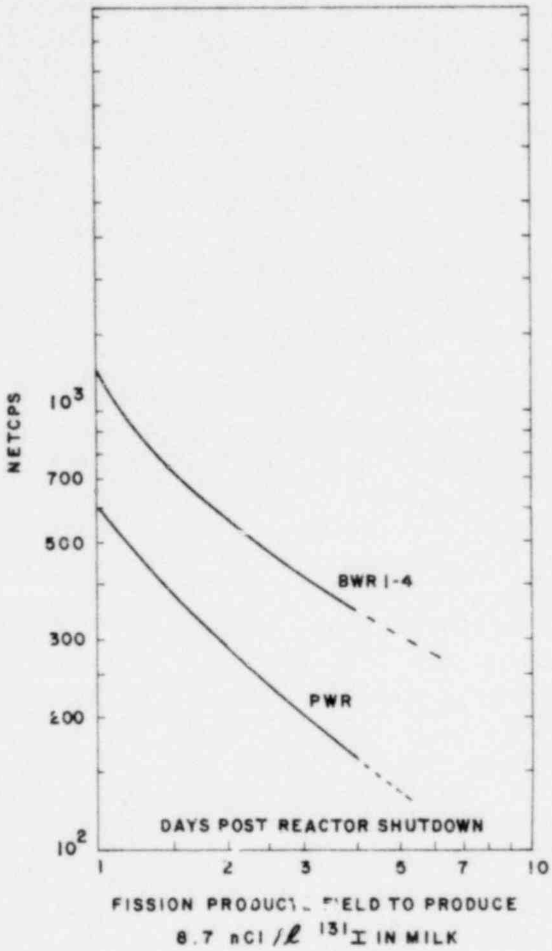


Figure 2.3 6306 Probe-on-Meter Response 1 Meter Above an Infinite Fission Products Field to Produce 8.7 nCi/ℓ ^{131}I in Milk

1322 265

3. DIRECT MILK AND WATER MONITORING

3.1 Introduction

Potable water can be supplied by wells, streams, reservoirs, and cisterns. Historically milk was collected in 40 quart cans. The current method used by large dairies, typical of northern New York State, is tank truck collection.

A common feature of water and milk monitoring was a lack of a consistent sampling geometry. For this reason two sampling methods were studied for detection efficiency and ease of use. The first consisted of a container with a monitoring port for GM probe measurements, and the other involved iodine trapping with bulk ion-exchange and measurement in an efficient, reproducible geometry.

Both methods employed GM probes and were sensitive to all gamma emitting fission products. The ion-exchange method of milk monitoring for radioiodine concentrated I^- but was inefficient for cations. Milk collected from farms contaminated by fission products will contain ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{89}Sr, ^{90}Sr, as well as the iodines. Cesium ions will not exchange with an appropriate anion exchange material that will be efficient for radioiodine. Since the strontrium and their chains are only beta emitters, closed probe measurements reflect a direct iodine response.

The container method of iodine sampling required an analysis of release fractions for various hypothetical reactor accidents. Calculations were made to account for the enhanced response due to the presence of the cesium group along with the iodines.

3.2 Bulk Ion-Exchange Method

The chloride form of Amberlite[14] IRA-900C was used as the exchange media. A 3500 cc water solution containing ^{131}I was placed in a one gallon plastic container. 200 cc of dry amberlite resin along with 25 mg of stable NaI carrier were introduced. The contents were mixed by rotating top to bottom for 1 minute, and the entire contents were rapidly strained through an empty, open, air sampling collector[15]. Victoreen probe[16] and standard, closed, D103 civil defense probes were introduced into the counting port for calibration. Results were 2525$\pm$1% net CPM/μCi/ℓ and 190$\pm$3% net CPM/μCi/ℓ for the 6306 and OCD-D-103 probes respectively. Ion Exchange bed efficiency was 63%.

1322 266

A measurement was made that allowed the ^{131}I test solution to drip slowly through an Amberlite resin filled air sampling collector. The drip rate of 3 ℓ/hr increased iodine exchange efficiency to over 80%. The relatively small efficiency improvement was not balanced by the much longer collection time, increased apparatus required, and clogging potential due to milk solids.

Radioiodine naturally secreted in milk appears as two chemical species with ~90%[1] available to anion exchange resins.

In WASH 1400[11], several radionuclides contained in milk that could cause significant human exposure were considered. They were ^{131}I, ^{133}I, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{136}Cs, and ^{137}Cs. As mentioned earlier, this anion exchange resin will trap the iodine but not the cesium. The strontium group is a beta emitter and will not be significantly measured by filtered GM detectors.

Drinking water was assumed to contain the same radionuclides as milk. In general, soluble molecules are expected suggesting salts of alkale metals, salts containing halogens, and nitrates. The halogens include iodine and will be trapped while the cations will not be retained.

Field use of the bulk ion exchange method for milk and water requires corrections. Adjustment must be made for the other members of the iodine family, and for milk the detector calibration factor must be reduced by 10% to account for the iodine bound by organics. Figure 3.1 contains the corrected results for the 6306 probe and the standard OCD-D-103 probe.

3.3 Iodine Measurement by the Container Method

The container[17] used was a 5 gallon heavy wall polyethylene "Jerri" type measuring 12x9x10 inches wide. The size was selected to insure near maximum counter efficiency[18] and to allow the results to be used directly with larger containers, including tank trucks. A 4.75 cm ID blind tube was installed to allow the GM probes to be positioned in the center of the container.

^{131}I was introduced into the container that was previously filled with 1/10 normal OH^- and an excess of stable I^-. Mixing was accomplished by cycling the container ten times through 180°. Probes were calibrated end down within the sampling container and on top of the container.

1322 267

Results are listed on Table 3.1 for three GM probe types and a commercial thin NaI scintillator. All instruments were connected to a scaler and accumulation times adjusted to reduce the counting error to less than 5%. The error limits given on Table 3.1 are one standard deviation of the mean of several determinations.

Use of the CDV 700 meter readout constrains the user to statistical uncertainties governed by the instrument time constant (R.C.). The standard deviation, s, of a gross single reading, a, in CPS is given by:

$$s = \sqrt{\frac{a}{2RC}} \text{ CPS}$$

where RC ≡ integrator time constant with R in ohms and C in farads.

The minimum detectable level, MDL, depends on the uncertainty ascribed to background. Taking 2s to be the MDL for the most sensitive range with a 6 second time constant, the MDL's range from 16 to 33 CPM. Comparing these values to the ^{131}I, calibration with probe inside container, sensitivities listed on Table 3.1 provided the MDL values for iodine shown below. The Victoreen probe is about 5 times

Probe	BKG(CPM)	MDL(CPM)	MDL(nCi/ℓ ^{131}I)
OCD-D-103	12	16	120
TGM	19	20	29
6306	55	33	23

more sensitive for near background levels and about 11 times more sensitive for ^{131}I concentrations of ≥ 1 µCi/ℓ.

Account must be made for the presence of ^{134}Cs, ^{136}Cs, and ^{137}Cs. The magnitude of the effect depends on the relative fractions of cesium to iodine released from a hypothetical reactor accident. The method used to account for the variability, due to differences in reactors and accident scenarios, was to determine the most probable 6306 probe sensitivity for PWR's and BWR's.

Deposition on pasture was assumed to be independent of radionuclide. Transport through a "typical" dairy herd was adopted from WASH 1400.

The 6306 probe sensitivity, s, in CPM per µCi/ℓ was given by:

$$s = \left(\frac{\text{CPM } ^{131}I}{\mu Ci/\ell}\right)\left(\frac{\text{CPM } \Sigma I}{\text{CPM } ^{131}I}\right)\left(\frac{\text{CPM } \Sigma \text{Fiss.P}}{\text{CPM } \Sigma I}\right)$$

1322 268

The fraction A(Isotope,t) appearing in milk from daily ingestion is given by[12]

$$A(Cs,t) = (.0138+.000073t)\ (1-e^{-.3t})\ \text{liter}^{-1}$$

$$A(I,t) = .0091\ e^{.021t}\ (1-e^{-.292t})\ \text{liter}^{-1}$$

Since

$$Q = C \times 45 \times \tfrac{1}{2} \times A \times L \times R\ \text{mCi}/\ell$$

where all variables are defined in part 2.3

$$\frac{Q(Cs,t)}{Q(I,t)} = \frac{\gamma(Cs)}{\gamma(I)} \times \frac{f(Cs,Accid)}{f(I,Accid)} \times \frac{A(Cs,t)}{A(I,t)} \times \frac{R(Cs,t)}{R(I,t)}$$

where $\gamma \equiv$ fission inventory

$f \equiv$ release fraction for a given accident

$$\frac{CPM(\Sigma Cs,t)}{CPM(\Sigma I,t)} = \frac{Q(Cs,t)}{Q(I,t)} \times \frac{CPM(\Sigma Cs,t)}{\text{Unit Act(to)}} \times \frac{\text{Unit Act(to)}}{CPM(\Sigma I,t)}$$

$$\frac{CPM(\Sigma Cs+\Sigma I,t)}{CPM(\Sigma I,t)} = \frac{CPM(\Sigma FissP,t)}{CPM(\Sigma I,t)} = 1 + \left[\frac{CPM(\Sigma Cs,t)}{CPM(\Sigma I,t)}\right]$$

Time, Days	1	2	4	8
$\frac{A(Cs,t)}{A(I,t)}$	1.5	1.5	1.5	1.4
$\frac{CPM\ \Sigma I(t)}{CPM\ ^{131}I(t)} \times \frac{CPM(^{131}I)}{\mu Ci/\ell}$	1790	1120	760	665

Results are shown on Table 3.2 and Figure 3.2 for 1 to 8 days after reactor shutdown and for PWR and BWR accidents. Calculations for the BWR results, Figure 3.2, indicate that the most probable and average probe sensitivity are similar. All of the 5 hypothetical BWR cases provide probe sensitivities within a factor of 2 of the most probable value. Uncertainties appear to be much larger for PWR accidents. The most probable sensitivity closely follows the locus of highest sensitivity. Table 3.2 provides a listing of 6306 probe sensitivity in CPM per $\mu Ci/\ell$ of ^{131}I for all the reactor accidents considered. PWR 9 has the largest probabily and the highest cesium to iodine release fraction. This single case dominates the probability weighted detector sensitivities.

1322 269

3.4 Discussion and Summary

The sensitivities of the bulk ion-exchange and container counting method may be compared. For milk monitoring one day after shutdown, the bulk ion-exchange and container method provide similar 6306 probe sensitivities for PWR accidents. Since the bulk ion-exchange method does not include the longer lived cesium isotopes, the sensitivity declines more rapidly than the container method. The overall sensitivity can be increased by using a larger volume of liquid. Use of 20 liters of liquid would increase the bulk ion-exchange sensitivity by factors of 2 to 5 depending on exchange efficiency. Assuming an improvement of 2, the 6306 probe would have a sensitivity, one day after release and shutdown, of about 1.2×10^4 CPM per µCi $^{131}I/\ell$. This would lead to a minimum detectable level of about 3 nCi $^{131}I/\ell$ with normal backgrounds. Thus two advantages exist for the bulk ion exchange method. The method is inherently more sensitive; since the iodine is concentrated by ion exchange and measured with higher efficiency. The required quantity is the radioiodine concentration in milk. The ion-exchange method discriminates against cation fission products, thus providing greater confidence in determining iodine concentration regardless of accident and reactor type.

1322 270

Table 3.1 Water and Milk Monitoring of ^{131}I with a 20 liter Container

Inst.[16]	BKG, CPM	Inside(Net CPM/μCi/ℓ)	Outside(Net CPM/μCi/ℓ)
OCD-D-103-1	12± 10%	132± 1%	55.7±3.7%
OCD-D-103-2	18± 7%	136±1.5%	56.1±7.1%
V-1	51.4± 3%	1370±1.9%	652± .7%
V-2	55.0± 5%	1519±1.1%	683±1.7%
V-3	54.6± 5%	1435±1.1%	640±3.1%
V-4	56.4± 5%	1489±1.5%	654±2.4%
TGM-1	18.5± 7%	703±2.3%	321± 4%
TGM-2	19.7± 7%	662±1.6%	300±3.7%
Ludlum	153±2.6%		8052± .6%

V = 6306 Probe

Table 3.2 GM Probe* Response to WASH 1400 Fission Products in Milk per μCi/ℓ ^{131}I

Accident	Probability	$\frac{f(Cs)}{f(I)}$	1 day	2 day	4 day	8 day
PWR 1	9×10^{-7}	.57	2115	1468	1167	1212
2	8×10^{-6}	.71	2198	1555	1268	1347
3	4×10^{-6}	.97	2350	1720	1458	1605
4	5×10^{-7}	.44	2040	1386	1072	1083
5	7×10^{-7}	.28	1951	1291	962	935
6	6×10^{-6}	.29	1954	1295	967	941
7	4×10^{-5}	.25	1933	1274	943	909
8	4×10^{-5}	4.76	4547	4067	4168	5266
9	4×10^{-4}	5.61	5036	4592	4774	5910
Probability Wt. Avg.			4635	4160	4455	5440
BWR 1	1×10^{-6}	.98	2357	1724	1463	1611
2	6×10^{-6}	.55	2107	1459	1156	1197
3	2×10^{-5}	.94	2329	1695	1430	1566
4	2×10^{-6}	3.33	3719	3183	3147	3886
5	1×10^{-4}	1.94	2913	2319	2150	2539
Probability Wt. Avg.			2795	2190	1990	2320

*6306 Probe[16]

1322 271

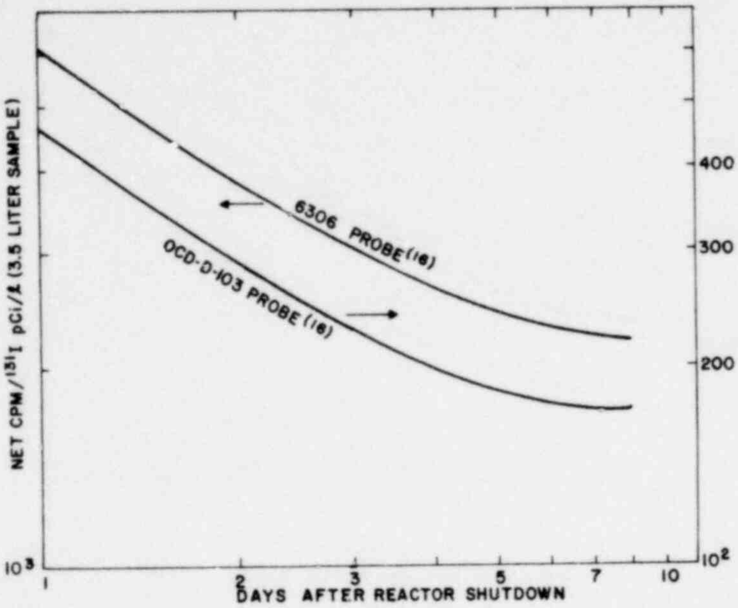


Figure 3.1 Milk Monitoring for ^{131}I by Bulk Ion Exchange

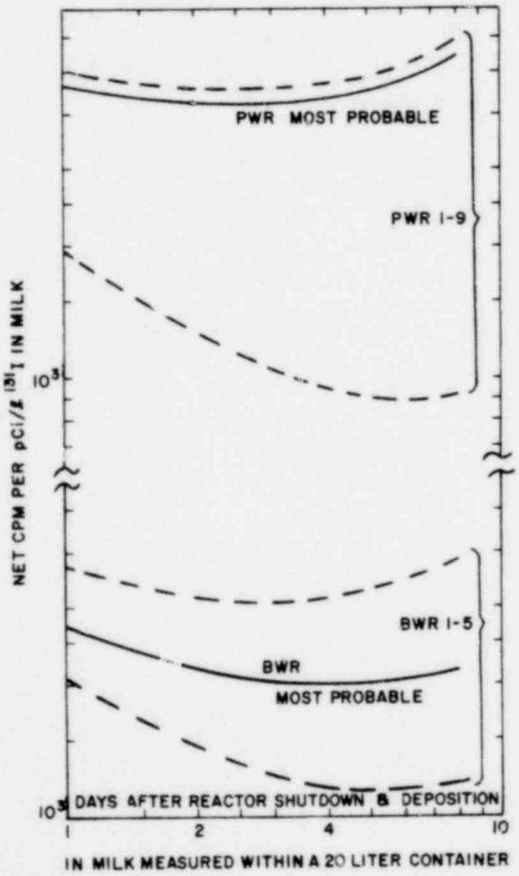


Figure 3.2 6306 Probe Response to WASH 1400 Fission Products in Milk Measured Within a 20 Liter Container

1322 272

4. HUMAN THYROID DOSE COMMITMENT PREDICTIONS

4.1 Introduction

Direct measurement of the radioiodine content of the thyroid can be used to predict the dose commitment. Field measurements of an exposed adult population could be used to set priorities for evacuation, for medical referral, and for confirmatory thyroid uptake determinations by qualified hospitals. Measurements, within a few hours after cloud passage, could be used to suggest administration of stable iodine to reduce the potential dose commitment.

The thyroid roughly resembles a butterfly and is located in the base of the neck. Most of the 20 gram mass is vertically arranged and the "wings" lie on either side of the trachea. The center of the thyroid is about 1 cm above the clavicle, but may lie below the clavicle in some people.

GM measurements can be made either with a probe arranged vertically along the front center of the neck, horizontally along the clavicle or end-on with the open window centered on the thyroid.

4.2 Methodology

Organ uptakes[19] are usually expressed as constant fractions of intake. Considering the short and variable decay times of the five fission iodine isotopes, metabolic and decay time must govern thyroid content for a given intake and time after intake. Realistically three time dependencies govern organ content; breathing time in the cloud (Δt), metabolic time ($\Delta t + t_2$) and decay time from some reference (t) govern the amount and composition of the five radioiodines in the thyroid. Berman[20] calculated the time dependent fraction f(t) of inhaled stable iodine reaching the adult thyroid for t_2 hours after intake.

$$f(t) = .235\ (e^{-.000453t_2} - e^{-.111t_2}) \qquad (1)$$

The measured counting rate, CPM, for radioiodine isotope i, with decay constant λi, for equilibrium fission yield[11] Y_i per 10^8 curies is given by equation 2

$$CPM = .235\ ZB\sum_{1-5}^{i} \left[R i Y_i e^{-\lambda i(t+t_2)} \int_{t_2}^{(t_2+\Delta t} (e^{-.000453t} - e^{-.111t})dt \right] \quad (2)$$

where Ri is the detector response relative to ^{131}I, Z is the adult thyroid phantom ^{131}I detector calibration factor in

1322 273

CPM/μCi, B is the breathing rate, and t_2 is the time of measurement after start of inhalation exposure.

The dose commitment H_∞ depends on the iodine activity in the thyroid integrated over 50 years and this is approximated by extending the integration limit to ∞.

$$H_\infty = \frac{B}{M} \sum_{1-5}^{i} e^{-\lambda i t} \frac{RiKi}{\lambda i}(1-e^{-\lambda i \Delta t}) \qquad (3)$$

where H_∞ is the committed thyroid dose in rem, Ki is defined[17] as .5928 $\Sigma FE_i(RBE)i$ x Ti where $\Sigma FEi(RBE)i$ is the decay chain energy absorbed by a critical organ per decay of parent i, and M is the thyroid organ mass of 16 grams. Table 4.1 is a listing of the ^{131}I calibration results for a number of detectors with an adult thyroid phantom[21]. Table 4.2 provides the values of R, Y, λ and K for the five iodine isotopes.

4.3 Results

The ratio of equations 2 and 3 supplies the relevant factor, CPM/H_∞, allowing a detector reading to be used to predict the dose commitment, at a given time after reactor shutdown, for a certain cloud breathing time and for a particular time after passage of the cloud. Results for radioiodine in adult thyroids detected by 6306 probes[16] are given on Figure 4.1 to 4.6 and in tabular form in the appendix. Figures 4.1 to 4.6, respectively, are for .5, 1, 2, 5, 10 and 18 hour cloud immersion times. Separate curves are drawn on each figure for various times after reactor shutdown to start of intake. The system of figures, or the tabular data in the appendix can be used to predict thyroid dose commitment from an instrument reading of radioiodine already in the thyroid.

For clarity, the use of the figures is illustrated. First select a figure corresponding to cloud immersion time. A time along the abscissa corresponding to the measurement time after reactor shutdown is followed to the correct time after shutdown to start of intake. The corresponding ordinate provides the 6306 probe dose commitment sensitivity factor. Other instrument probes can be used by adjusting the detector-dose commitment interpretation by the ratio of a phantom calibration for a different detector, given in Table 4.1, to the Victoreen probe calibration for horizontal probe geometry.

The approximate minimum detectable thyroid dose commitment,

1322 274

MDDC, for a cloud immersion of 1 hour starting immediately after shutdown and measured 300 hours later is about 2 rem. Reducing the measurement delay time to four days improves the MDDC to <1 rem.

It may be useful to consider the WASH 1400[11] release from containment accident cases. Assuming a wind speed of 1 m/s and a thyroid measurement made 4 hours after cloud passage, 0.6 rem is the MDDC, Table 4.3.

4.4 Discussion

The above method depends on use of an ADULT thyroid phantom, a metabolic prescription for general populations, and calculational parameters for adults. The technique could be adapted for use with children, but only if significant parametric adjustments were made. The infant thyroid lobes[22] have about half the diameter of adult lobes and are covered by about .73 cm of tissue compared to 1 to 2 cm for an adult[22]. Instrument response, per unit radioiodine in the thyroid, would be somewhat greater for the child than the adult, but the smaller gland results is a lower overall reading per rem. Therefore, adjustments for tissue shielding and organ mass are necessary to predict a correct response.

Sensitivity of the method depends on a normal instrument background to detect 2 rem. Monitoring sites must be selected for normal, natural background readings with the same instrument types that are to be used for personnel screening. Use can be made of available structures for shielding. Below grade basement corner locations may have adequate background readings, assuming somewhat elevated values are observed outdoors.

Personnel to be monitored must be premeasured for surface contamination with standard open probe CDV-700 instruments. Change of clothing and decontamination by washing are necessary to remove surface contamination prior to thyroid measurement for minimum detectable dose commitments.

Radioiodine thyroid measurements must be made with closed probe standard CDV-700 or other instruments listed on Table 1 for the results presented to be applicable. The probe should be centered on the front lower neck along the clavicle. Background meter readings must be subtracted from thyroid readings. The difference or net readings are used to predict the dose commitment.

Greater instrument sensitivity and accuracy can be obtained by counting the audible signal provided by the earphones for a predetermined length of time such as a minute. Again, a net value of counts per minute, CPM, is needed. This requires a similar audible count of background to be made and subtracted from the thyroid monitor measurement.

4.5 Summary

Direct measurement of radioiodine in adult thyroids can be used to predict dose commitment. Care must be taken in the selection of monitoring locations so that normal, natural background will allow thyroid uptake measurements to be made with optimum sensitivity. Minimum detectable dose commitment values of .2 to .6 rem were calculated for the nine PWR and five BWR hypothetical release from containment accidents outlined in WASH 1400 using a 6306 probe. The method must not be applied to children without detailed adjustment in the results given.

1322 276

Table 4.1 Thyroid Phantom Calibrations for ^{131}I

Inst.[24]	Probe Orientation: Vertical	Horizontal	10 cm away (Net CPM/μCi in organ)	End-on
OCD-D-103-1	44 ± 3.2%	47 ± 1.7%		
OCD-D-103-2	42 ± 3.2%	49 ± 2.2%	6.5 ± 2.4%	
V-1	446 ± 1.3%	453 ± 1.6%	75.4 ± 2.5%	
V-2	486 ± 1.3%	517 ± 1.2%	87.7 ± 1.5%	
V-3	406 ± 1.6%	476 ± 1.1%	72.4 ± 3.4%	
V-4	428 ± 1.8%	511 ± .9%	76.2 ± 2.2%	
TGM-1	214 ± 3.0%	245 ± 1.8%	35.5 ± 3.6%	
TGM-2	252 ± 2.7%	266 ± 1.9%	36.1 ± 2.1%	
Ludlum			574 ± 3.4%	4890 ± .4%

V = 6306 Probe[16]

Ludlum[23], Model 44-3

Table 4.2 Parameters Used to Calculate Thyroid Uptake

Ii	R	Y	λ hrs^{-1}	K
^{131}I	1	1	.003581	5.997
^{132}I	4.468	1.412	.30347	.0575
^{133}I	1.372	2.0	.03332	.0264
^{134}I	4.737	2.235	.7952	.0132
^{135}I	2.231	1.765	.10345	.2765

R = Detector Response Relative to ^{131}I

Y = Fission Yield Per 10^8 Curie

λ = Decay Constant, Hrs

K = .5928 ΣFEi(RBE)i x Ti[17]

1322 277

Table 4.3 Minimum Detectable Dose Commitments 5, 10, and 30 Miles from PWR and BWR Accidents for a Wind Speed of 1 m/s and for the 6306 Probe

Release Category	Time of Release(hr)	Duration of Release(hr)	~Minimum Detectable Dose Commitment, Rem* 5 mi.	10 mi.	30 mi.
PWR 1	2.5	.5	.3	.4	.5
PWR 2	2.5	.5	.3	.4	.5
PWR 3	5	1.5	.3	.3	.4
PWR 4	2	3	.3	.3	.4
PWR 5	2	4	.2	.3	.4
PWR 6	12	10	.3	.3	.4
PWR 7	10	10	.3	.3	.4
PWR 8	.5	.5	.3	.3	.5
PWR 9	.5	.5	.3	.3	.5
BWR 1	2	.5	.3	.4	.5
BWR 2	30	3	.5	.5	.6
BWR 3	30	3	.5	.5	.6
BWR 4	5	2	.3	.3	.4
BWR 5	3.5	5	.2	.3	.4

*To adult thyroid

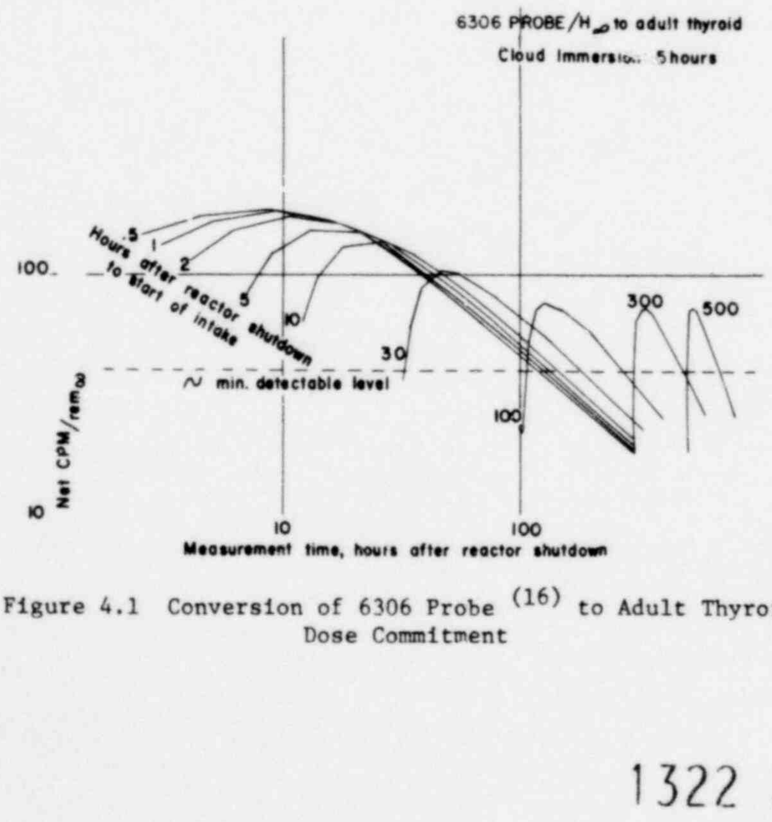


Figure 4.1 Conversion of 6306 Probe [16] to Adult Thyroid Dose Commitment

1322 278

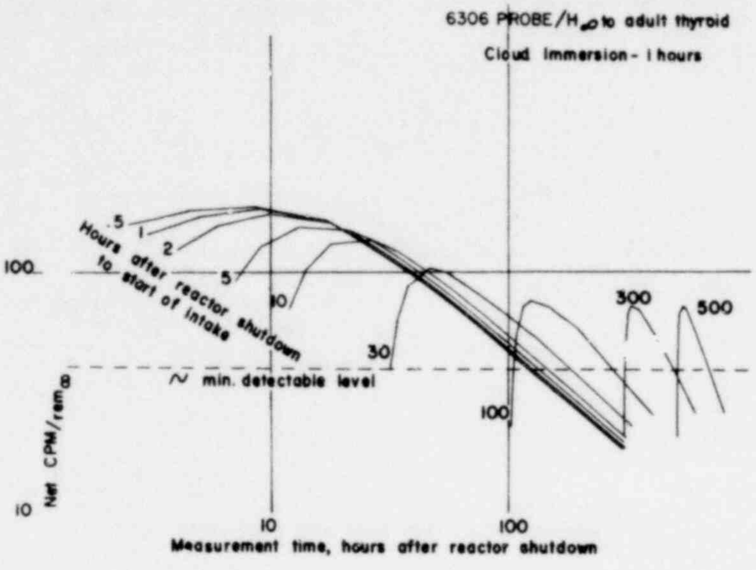


Figure 4.2 Conversion of 6306 Probe (16) to Adult Thyroid Dose Commitment

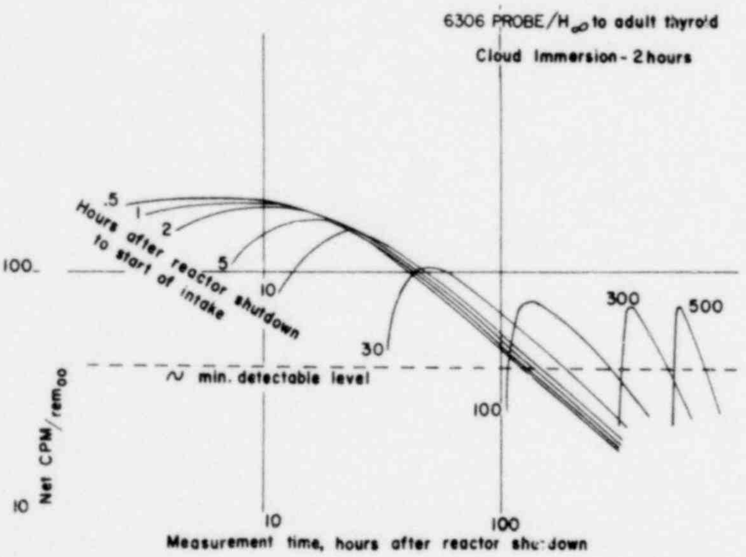


Figure 4.3 Conversion of 6306 Probe (16) to Adult Thyroid Dose Commitment

1322 279

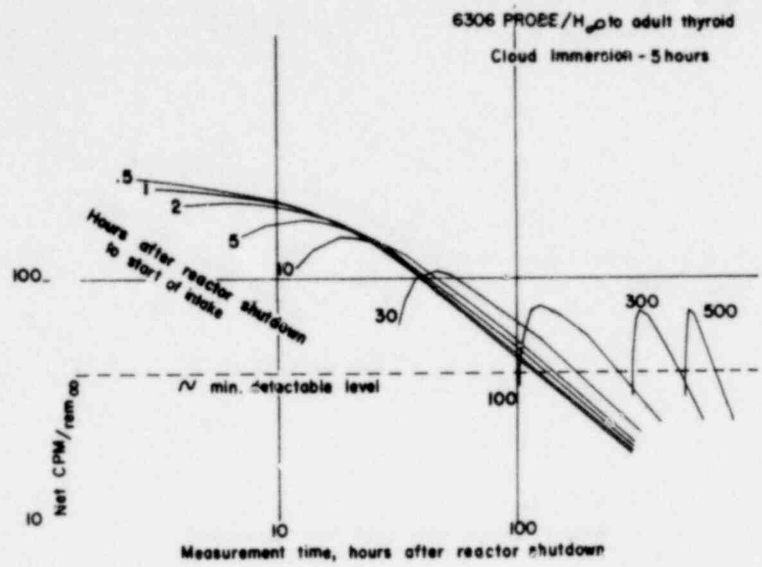


Figure 4.4 Conversion of 6306 Probe (16) to Adult Thyroid Dose Commitment

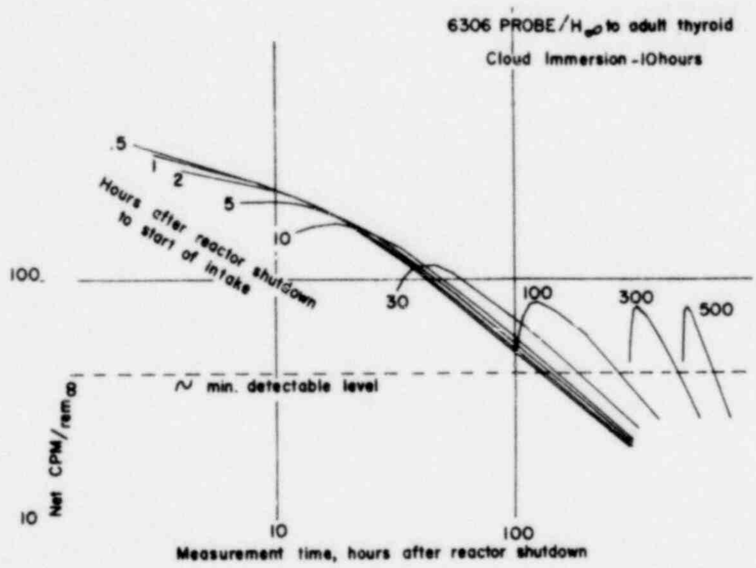


Figure 4.5 Conversion of 6306 Probe (16) to Adult Thyroid Dose Commitment

1322 280

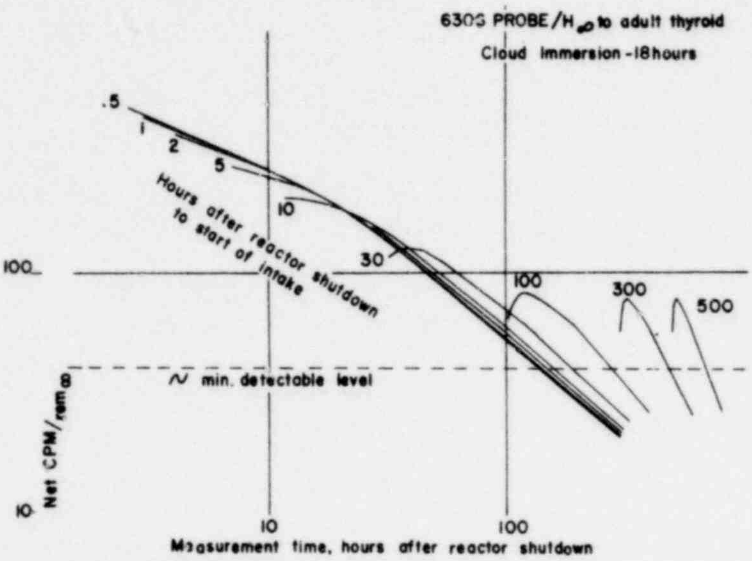


Figure 4.6 Conversion of 6306 Probe (16) to Adult Thyroid Dose Commitment

1322 281

References

1. Miller, J. K., et.al., "Iodine Absorption, Excretion, Recycling and Tissue Distribution in the Dairy Cow", J. of Dairy Sci. 58, pp. 1578-1593, October 1975.

2. Blincoe, C., "Computer Simulation of Iodine Metabolism by Mammals", J. of Anim. Sci. 40 #2, 1975.

3. Swanson, E. W., Lengemann, F. W., et.al., "Factors Affecting the Thyroid Uptake of ^{131}I in Dairy Cows", J. Anim. Sci. 16:318, 1957.

4. Hemken, R. W., et.al., "Iodine Intake Related to Milk Iodine and Performance of Dairy Cattle", J. Dairy Sci. 55:931, 1972.

5. Hemken, R. W., et.al., "Goitrogenic Effects of a Corn Silage-Soybean Meal Supplemented Ration", J. Dairy Sci. 54:85, 1971.

6. Sisson and Grossman's "The Anatomy of the Domestic Animals" 5th Ed, Vol. 1, p. 918, 920, W. B. Sounders Co., Phila. PA.

7. Haynes, F. C., "Design Calculations for a Sub-Infinite ^{131}I Fallout Field", 1977 Summer Study, BNL.

8. Fisher Scientific Co., 52 Fadem Road, Springfield, N. J.

9. Goldstein, H., "Fundamental Aspects of Reactor Shielding", Reading, Mass., Addison-Wesley, 1959.

10. Goldstein, H., et.al., "Calculations of the Penetration of Gamma Rays", NYO-3075, 1954.

11. Nuclear Regulatory Commission, "Reactor Safety Study", App. VI, WASH 1400, 1975.

12. Lengemann, F. W., "Predicting the Total Projected Intake of Radioiodine from Milk by Man", Part 1, Health Physics 12, pp. 825-830, 1966.

13. Distenfeld, C. H., Klemish, J. R., "Monitoring of Radioiodine fron Containment Accidents", BNL 23112, June 1977.

14. Alfa Division of Ventron Corp., Danvers, Mass.

15. Distenfeld, C. H., Klemish, J. R., "High Efficiency Mixed Species Radioiodine Air Sampling, Readout and Dose Assessment System", BNL 21541, May 1976.

16. Distenfeld, C. H., Klemish, J. R., "An Air Sampling System for Evaluating the Thyroid Dose Commitment Due to Fission Products Released from Reactor Containment", NUREG/CR-0314, 1978.

1322 282

17. Scepterene Products, Dillon Beck Manuf. Co., Hillside, N. J.

18. IAEA, "Environmental Monitoring in Emergency Situations", SSIB, Vienna, 1966.

19. Report of ICRP Committee II on Permissible Dose for Internal Radiation, Health Physics 3, June 1960.

20. Berman, M., et.al., "MIRD/Dose Estimate Report No. 5", J. of Nuc. Med. 16, No. 9, 1975.

21. Nuclear Associates, Inc., Model 74-350, Westbury, N. Y.

22. ICRP Report No. 23, "Report on the Task Group on Reference Man", Pergamon Press, New York, 1975.

23. Ludlum Measurements, Inc.
501 Oak Street
Sweetwater, Texas 79556

1322 283

Appendix A

Adult Thyroid Dose Commitment as a Function of Victoreen Probe Response for Direct Thyroid Uptake Measurements

where

H(inf) - rem dose commitment to the thyroid

t_2 - time of measurement in hours after reactor shutdown

dt - hours in the cloud

t - hours after reactor shutdown to start of intake

1322 284

TIME IN CLOUD= 0.5

IODINE RESIDENCE TIME IN BODY=2

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
156.455	1.021	153.3	0.00652	2.0	0.0	0.5
138.760	1.010	137.4	0.00728	2.5	0.5	0.5
124.981	1.000	125.0	0.00800	3.0	1.0	0.5
105.136	0.982	107.1	0.00934	4.0	2.0	0.5
74.081	0.935	79.3	0.01262	7.0	5.0	0.5
51.926	0.872	59.6	0.01679	12.0	10.0	0.5
25.074	0.712	35.2	0.02838	32.0	30.0	0.5
9.948	0.481	20.7	0.04837	102.0	100.0	0.5
4.294	0.230	18.7	0.05361	302.0	300.0	0.5
2.098	0.112	18.6	0.05363	502.0	500.0	0.5
0.350	0.019	18.6	0.05363	1002.0	1000.0	0.5

IODINE RESIDENCE TIME IN BODY=4

178.866	1.021	175.2	0.00571	4.0	0.0	0.5
166.356	1.010	164.7	0.00607	4.5	0.5	0.5
155.822	1.000	155.8	0.00642	5.0	1.0	0.5
138.992	0.982	141.6	0.00706	6.0	2.0	0.5
107.099	0.935	114.6	0.00873	9.0	5.0	0.5
79.425	0.872	91.1	0.01098	14.0	10.0	0.5
40.627	0.712	57.1	0.01752	34.0	30.0	0.5
16.691	0.481	34.7	0.02883	104.0	100.0	0.5
7.254	0.230	31.5	0.03174	304.0	300.0	0.5
3.543	0.112	31.5	0.03175	504.0	500.0	0.5
0.591	0.019	31.5	0.03175	1004.0	1000.0	0.5

IODINE RESIDENCE TIME IN BODY=8

184.263	1.021	180.5	0.00554	8.0	0.0	0.5
177.140	1.010	175.4	0.00570	8.5	0[illegible]	0.5
170.632	1.000	170.6	0.00586	9.0	1.0	0.5
159.147	0.982	162.1	0.00617	10.0	2.0	0.5
133.223	0.935	142.5	0.00702	13.0	5.0	0.5
105.771	0.872	121.3	0.00824	18.0	10.0	0.5
59.147	0.712	83.1	0.01203	38.0	30.0	0.5
25.887	0.481	53.8	0.01859	108.0	100.0	0.5
11.392	0.230	49.5	0.02021	308.0	300.0	0.5
5.565	0.112	49.5	0.02021	508.0	500.0	0.5
0.929	0.019	49.5	0.02021	1008.0	1000.0	0.5

IODINE RESIDENCE TIME IN BODY=16

159.975	1.021	156.7	0.00638	16.0	0.0	0.5
156.488	1.010	154.9	0.00646	16.5	0.5	0.5
153.160	1.000	153.1	0.00653	17.0	1.0	0.5
146.936	0.982	149.7	0.00668	18.0	2.0	0.5
131.085	0.935	140.2	0.00713	21.0	5.0	0.5
111.294	0.872	127.6	0.00783	26.0	10.0	0.5
70.288	0.712	98.8	0.01012	46.0	30.0	0.5
34.209	0.481	71.1	0.01407	116.0	100.0	0.5
15.378	0.230	66.8	0.01497	316.0	300.0	0.5
7.512	0.112	66.8	0.01497	516.0	500.0	0.5
1.254	0.019	66.8	0.01497	1016.0	1000.0	0.5

IODINE RESIDENCE TIME IN BODY=24

131.770	1.021	129.1	0.00775	24.0	0.0	0.5
129.691	1.010	128.4	0.00779	24.5	0.5	0.5
127.678	1.000	127.7	0.00783	25.0	1.0	0.5
123.841	0.982	126.1	0.00793	26.0	2.0	0.5
113.643	0.935	121.6	0.00822	29.0	5.0	0.5
100.057	0.872	114.8	0.00871	34.0	10.0	0.5
68.578	0.712	96.4	0.01038	54.0	30.0	0.5
36.362	0.481	75.6	0.01323	124.0	100.0	0.5
16.628	0.230	72.2	0.01385	324.0	300.0	0.5
8.123	0.112	72.2	0.01385	524.0	500.0	0.5
1.356	0.019	72.2	0.01385	1024.0	1000.0	0.5

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=48						
79.821	1.021	78.2	0.01279	48.0	0.0	0.5
79.146	1.010	78.3	0.01276	48.5	0.5	0.5
78.483	1.000	78.5	0.01274	49.0	1.0	0.5
77.193	0.982	78.6	0.01272	50.0	2.0	0.5
73.593	0.935	78.7	0.01270	53.0	5.0	0.5
68.362	0.872	78.4	0.01275	58.0	10.0	0.5
53.903	0.712	75.7	0.01320	78.0	30.0	0.5
34.107	0.481	70.9	0.01411	148.0	100.0	0.5
16.124	0.230	70.0	0.01428	348.0	300.0	0.5
7.677	0.112	70.0	0.01428	548.0	500.0	0.5
1.315	0.019	70.0	0.01428	1048.0	1000.0	0.5
IODINE RESIDENCE TIME IN BODY=96						
45.266	1.021	44.3	0.02255	96.0	0.0	0.5
45.094	1.010	44.6	0.02240	96.5	0.5	0.5
44.923	1.000	44.9	0.02226	97.0	1.0	0.5
44.588	0.982	45.4	0.02202	98.0	[illegible]	0.5
43.621	0.935	46.7	0.02143	101.0	5.0	0.5
42.136	0.872	48.3	0.02069	106.0	10.0	0.5
37.374	0.712	52.5	0.01904	126.0	30.0	0.5
27.540	0.481	57.2	0.01747	196.0	100.0	0.5
13.349	0.230	58.0	0.01725	396.0	300.0	0.5
6.522	0.112	58.0	0.01725	596.0	500.0	0.5
1.088	0.019	58.0	0.01725	1096.0	1000.0	0.5
IODINE RESIDENCE TIME IN BODY=300						
17.170	1.021	16.8	0.05946	300.0	0.0	0.5
17.139	1.010	17.0	0.05894	300.5	0.5	0.5
17.108	1.000	17.1	0.05846	301.0	1.0	0.5
17.047	0.982	17.4	0.05759	302.0	2.0	0.5
16.864	0.935	18.0	0.05542	305.0	5.0	0.5
16.564	0.872	19.0	0.05264	310.0	10.0	0.5
15.417	0.712	21.7	0.04616	330.0	30.0	0.5
[illegible]	0.481	24.9	0.04011	400.0	100.0	0.5
[illegible]	0.230	25.5	0.03928	600.0	300.0	0.5
[illegible]	0.112	25.5	0.03927	800.0	500.0	0.5
0.478	0.019	25.5	0.03927	1300.0	1000.0	0.5
TIME IN CLOUD= 1						
IODINE RESIDENCE TIME IN BODY=2						
342.677	2.031	168.7	0.00593	2.0	0.0	1.0
303.921	2.010	151.2	0.00661	2.5	0.5	1.0
273.741	1.991	137.5	0.00727	3.0	1.0	1.0
230.276	1.955	117.8	0.00849	4.0	2.0	1.0
162.258	1.862	87.1	0.01148	7.0	5.0	1.0
113.732	1.738	65.4	0.01528	12.0	10.0	1.0
54.919	1.420	38.7	0.02586	32.0	30.0	1.0
21.790	0.961	22.7	0.04413	102.0	100.0	1.0
9.406	0.460	20.4	0.04891	302.0	300.0	1.0
4.594	0.225	20.4	0.04892	502.0	500.0	1.0
0.767	0.038	20.4	0.04892	1002.0	1000.0	1.0
IODINE RESIDENCE TIME IN BODY=4						
373.731	2.031	184.0	0.00543	4.0	0.0	1.0
347.592	2.010	172.9	0.00578	4.5	0.5	1.0
325.583	1.991	163.5	0.00612	5.0	1.0	1.0
290.418	1.955	148.6	0.00673	6.0	2.0	1.0
223.778	1.862	120.2	0.00832	9.0	5.0	1.0
165.955	1.738	95.5	0.01047	14.0	10.0	1.0
84.888	1.420	59.8	0.01673	34.0	30.0	1.0
34.874	0.961	36.3	0.02757	104.0	100.0	1.0
15.156	0.460	32.9	0.03035	304.0	300.0	1.0
7.403	0.225	32.9	0.03036	504.0	500.0	1.0
1.235	0.038	32.9	0.03036	1004.0	1000.0	1.0

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=8						
375.138	2.031	184.7	0.00541	8.0	0.0	1.0
360.635	2.010	179.4	0.00557	8.5	0.5	1.0
347.386	1.991	174.5	0.00573	9.0	1.0	1.0
324.003	1.955	165.7	0.00603	10.0	2.0	1.0
271.226	1.862	145.6	0.00687	13.0	5.0	1.0
215.336	1.738	123.9	0.00807	18.0	10.0	1.0
120.417	1.420	84.8	0.01179	38.0	30.0	1.0
52.703	0.961	54.8	0.01824	108.0	100.0	1.0
23.193	0.460	50.4	0.01984	308.0	300.0	1.0
11.329	0.225	50.4	0.01984	508.0	500.0	1.0
1.891	0.038	50.4	0.01984	1008.0	1000.0	1.0
IODINE RESIDENCE TIME IN BODY=16						
321.624	2.031	158.4	0.00631	16.0	0.0	1.0
314.615	2.010	156.5	0.00639	16.5	0.5	1.0
307.924	1.991	154.7	0.00647	17.0	1.0	1.0
295.411	1.955	151.1	0.00662	18.0	2.0	1.0
263.542	1.862	141.5	0.00707	21.0	5.0	1.0
223.753	1.738	128.7	0.00777	26.0	10.0	1.0
141.311	1.420	99.5	0.01005	46.0	30.0	1.0
68.776	0.961	71.5	0.01398	116.0	100.0	1.0
30.917	0.460	67.2	0.01488	316.0	300.0	1.0
15.103	0.225	67.2	0.01488	516.0	500.0	1.0
2.520	0.038	67.2	0.01488	1016.0	1000.0	1.0
IODINE RESIDENCE TIME IN BODY=24						
264.032	2.031	130.0	0.00769	24.0	0.0	1.0
259.865	2.010	129.3	0.00774	24.5	0.5	1.0
255.832	1.991	128.5	0.00778	25.0	1.0	1.0
248.143	1.955	126.9	0.00788	26.0	2.0	1.0
227.710	1.862	122.3	0.00818	29.0	5.0	1.0
200.487	1.738	115.3	0.00867	34.0	10.0	1.0
137.411	1.420	96.7	0.01034	54.0	30.0	1.0
72.860	0.961	75.8	0.01320	124.0	100.0	1.0
33.317	0.460	72.4	0.01381	324.0	300.0	1.0
16.276	0.225	72.4	0.01381	524.0	500.0	1.0
2.716	0.038	72.4	0.01381	1024.0	1000.0	1.0
IODINE RESIDENCE TIME IN BODY=48						
159.645	2.031	78.6	0.01272	48.0	0.0	1.0
158.294	2.010	78.7	0.01270	48.5	0.5	1.0
156.968	1.991	78.8	0.01268	49.0	1.0	1.0
154.389	1.955	79.0	0.01266	50.0	2.0	1.0
147.188	1.862	79.0	0.01265	53.0	5.0	1.0
136.727	1.738	78.7	0.01271	58.0	10.0	1.0
107.808	1.420	75.9	0.01317	78.0	30.0	1.0
68.215	0.961	70.9	0.01409	148.0	100.0	1.0
32.248	0.460	70.1	0.01427	348.0	300.0	1.0
15.755	0.225	70.1	0.01427	548.0	500.0	1.0
2.629	0.038	70.1	0.01427	1048.0	1000.0	1.0
IODINE RESIDENCE TIME IN BODY=96						
90.523	2.031	44.6	0.02244	96.0	0.0	1.0
90.178	2.010	44.9	0.02229	96.5	0.5	1.0
89.837	1.991	45.1	0.02216	97.0	1.0	1.0
89.165	1.955	45.6	0.02193	98.0	2.0	1.0
87.233	1.862	46.8	0.02135	101.0	5.0	1.0
84.262	1.738	48.5	0.02063	106.0	10.0	1.0
74.740	1.420	52.6	0.01900	126.0	30.0	1.0
55.073	0.961	57.3	0.01746	196.0	100.0	1.0
26.694	0.460	58.0	0.01723	396.0	300.0	1.0
13.043	0.225	58.0	0.01723	596.0	500.0	1.0
2.177	0.038	58.0	0.01723	1096.0	1000.0	1.0

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=300						
34.335	2.031	16.9	0.05915	300.0	0.0	1.0
34.274	2.010	17.0	0.05866	300.5	0.5	1.0
34.212	1.991	17.2	0.05819	301.0	1.0	1.0
34.090	1.955	17.4	0.05735	302.0	2.0	1.0
33.724	1.862	18.1	0.05522	305.0	5.0	1.0
33.124	1.738	19.1	0.05248	310.0	10.0	1.0
30.831	1.420	21.7	0.04607	330.0	30.0	1.0
23.992	0.961	25.0	0.04007	400.0	100.0	1.0
11.722	0.460	25.5	0.03924	600.0	300.0	1.0
5.728	0.225	25.5	0.03924	800.0	500.0	1.0
0.956	0.038	25.5	0.03924	1300.0	1000.0	1.0
TIME IN CLOUD= 2						
IODINE RESIDENCE TIME IN BODY=2						
798.046	4.022	198.4	0.00504	2.0	0.0	2.0
707.789	3.983	177.7	0.00563	2.5	0.5	2.0
637.304	3.946	161.6	0.00619	3.0	1.0	2.0
536.280	3.877	138.3	0.00723	4.0	2.0	2.0
377.875	3.697	102.2	0.00978	7.0	5.0	2.0
264.866	3.455	76.7	0.01304	12.0	10.0	2.0
127.899	2.829	45.2	0.02212	32.0	30.0	2.0
50.745	1.919	26.4	0.03782	102.0	100.0	2.0
21.905	0.918	23.9	0.04193	302.0	300.0	2.0
10.699	0.449	23.8	0.04194	502.0	500.0	2.0
1.785	0.075	23.8	0.04194	1002.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=4						
808.029	4.022	200.9	0.00498	4.0	0.0	2.0
751.515	3.983	188.7	0.00530	4.5	0.5	2.0
703.930	3.946	178.4	0.00561	5.0	1.0	2.0
627.900	3.877	162.0	0.00617	6.0	2.0	2.0
483.821	3.697	130.9	0.00764	9.0	5.0	2.0
358.805	3.455	103.9	0.00963	14.0	10.0	2.0
183.534	2.829	64.9	0.01541	34.0	30.0	2.0
75.400	1.919	39.3	0.02545	104.0	100.0	2.0
32.769	0.918	35.7	0.02803	304.0	300.0	2.0
16.006	0.449	35.7	0.02804	504.0	500.0	2.0
2.671	0.075	35.7	0.02804	1004.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=8						
775.297	4.022	192.8	0.00519	8.0	0.0	2.0
745.324	3.983	187.1	0.00534	8.5	0.5	2.0
717.943	3.946	181.9	0.00550	9.0	1.0	2.0
669.617	3.877	172.7	0.00579	10.0	2.0	2.0
560.543	3.697	151.6	0.00660	13.0	5.0	2.0
445.035	3.455	128.8	0.00776	18.0	10.0	2.0
248.866	2.829	88.0	0.[illegible]137	38.0	30.0	2.0
108.922	1.919	56.8	0.0[illegible]762	108.0	100.0	2.0
47.933	0.918	52.2	0.01916	308.0	300.0	2.0
23.413	0.449	52.2	0.01917	508.0	500.0	2.0
3.907	0.075	52.2	0.01917	1008.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=16						
649.581	4.022	161.5	0.00619	16.0	0.0	2.0
635.424	3.983	159.5	0.00627	16.5	0.5	2.0
621.911	3.946	157.6	0.00634	17.0	1.0	2.0
596.638	3.877	153.9	0.00650	18.0	2.0	2.0
532.273	3.697	144.0	0.00695	21.0	5.0	2.0
451.912	3.455	130.8	0.00765	26.0	10.0	2.0
285.405	2.829	100.9	0.00991	46.0	30.0	2.0
138.906	1.919	72.4	0.01381	116.0	100.0	2.0
62.442	0.918	68.0	0.01471	316.0	300.0	2.0
30.503	0.449	68.0	0.01471	516.0	500.0	2.0
5.090	0.075	68.0	0.01471	1016.0	1000.0	2.0

1322 288

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=24						
529.918	4.022	131.8	0.00759	24.0	0.0	2.0
521.554	3.983	130.[illegible]	0.00764	24.5	0.5	2.0
513.460	3.946	130.1	0.00769	25.0	1.0	2.0
498.028	3.877	128.5	0.00778	26.0	2.0	2.0
457.019	3.697	123.6	0.00809	29.0	5.0	2.0
402.381	3.455	116.5	0.00859	34.0	10.0	2.0
275.787	2.829	97.5	0.01026	54.0	30.0	2.0
146.231	1.919	76.2	0.01312	124.0	100.0	2.0
66.868	0.918	72.8	0.01374	324.0	300.0	2.0
32.666	0.449	72.8	0.01374	524.0	500.0	2.0
5.451	0.075	72.8	0.01374	1024.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=48						
319.297	4.022	79.4	0.01260	48.0	0.0	2.0
[illegible]595	3.983	79.5	0.01258	48.5	0.5	2.0
313.943	3.946	79.6	0.01257	49.0	1.0	2.0
308.784	3.877	79.6	0.01256	50.0	2.0	2.0
294.382	3.697	79.6	0.01256	53.0	5.0	2.0
273.459	3.455	79.2	0.01263	58.0	10.0	2.0
215.620	2.829	76.2	0.01312	[illegible]3.0	30.0	2.0
136.432	1.919	71.1	0.01407	148.0	100.0	2.0
64.497	0.918	70.2	0.01424	348.0	300.0	2.0
31.511	0.449	70.2	0.01424	548.0	500.0	2.0
5.258	0.075	70.2	0.01424	1048.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=96						
181.004	4.022	45.0	0.02222	96.0	0.0	2.0
180.315	3.983	45.3	0.02209	96.5	0.5	2.0
179.633	3.946	45.5	0.02197	97.0	1.0	2.0
178.290	3.877	46.0	0.02175	98.0	2.0	2.0
174.426	3.697	47.2	0.02120	101.0	5.0	2.0
168.485	3.455	48.8	0.02051	106.0	10.0	2.0
149.446	2.829	52.8	0.01893	126.0	30.0	2.0
110.121	1.919	57.4	0.01743	196.0	100.0	2.0
53.376	0.918	58.1	0.01721	396.0	300.0	2.0
26.079	0.449	58.1	0.01721	596.0	500.0	2.0
4.352	0.075	58.1	0.01721	1096.0	1000.0	2.0
IODINE RESIDENCE TIME IN BODY=300						
68.655	4.022	17.1	0.05858	300.0	0.0	2.0
68.532	3.983	17.2	0.05812	300.5	0.5	2.0
68.409	3.946	17.3	0.05768	301.0	1.0	2.0
68.164	3.877	17.6	0.05688	302.0	2.0	2.0
67.433	3.697	18.2	0.05483	305.0	5.0	2.0
66.234	3.455	19.2	0.05216	310.0	10.0	2.0
61.649	2.829	21.8	0.04589	330.0	30.0	2.0
47.973	1.919	25.0	0.04000	400.0	100.0	2.0
23.440	0.918	25.5	0.03918	600.0	300.0	2.0
11.453	0.449	25.5	0.03918	800.0	500.0	2.0
1.911	0.075	25.5	0.03918	1200.0	1000.0	2.0
TIME IN CLOUD= 5						
IODINE RESIDENCE TIME IN BODY=2						
2727.365	9.790	278.6	0.00359	2.0	0.0	5.0
2418.908	9.704	249.3	0.00401	2.5	0.5	5.0
2178.705	9.621	226.4	0.00442	3.0	1.0	5.0
1832.765	9.466	193.6	0.00516	4.0	2.0	5.0
1291.410	9.052	142.7	0.00701	7.0	5.0	5.0
905.193	8.483	106.7	0.00937	12.0	10.0	5.0
437.103	6.989	62.5	0.01599	32.0	30.0	5.0
173.424	4.768	36.4	0.02749	102.0	100.0	5.0
74.862	2.284	32.8	0.03051	302.0	300.0	5.0
36.565	1.116	32.8	0.03052	502.0	500.0	5.0
6.102	0.186	32.8	0.03052	1002.0	1000.0	5.0

1322 289

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=4						
2413.534	9.790	246.5	0.00406	4.0	0.0	5.0
2244.730	9.704	231.3	0.00432	4.5	0.5	5.0
2102.596	9.621	218.5	0.00458	5.0	1.0	5.0
1875.498	9.466	198.1	0.00505	6.0	2.0	5.0
1445.144	9.052	159.7	0.00626	9.0	5.0	5.0
1071.728	8.483	126.3	0.00792	14.0	10.0	5.0
548.204	6.989	78.4	0.01275	34.0	30.0	5.0
225.215	4.768	47.2	0.02117	104.0	100.0	5.0
97.879	2.284	42.9	0.02333	304.0	300.0	5.0
47.809	1.116	42.8	0.02334	504.0	500.0	5.0
7.978	0.186	42.8	0.02334	1004.0	1000.0	5.0
IODINE RESIDENCE TIME IN BODY=8						
2100.691	9.790	214.6	0.00466	8.0	0.0	5.0
2019.479	9.704	208.1	0.00481	8.5	0.5	5.0
1945.289	9.621	202.2	0.00495	9.0	1.0	5.0
1814.349	9.466	191.7	0.00522	10.0	2.0	5.0
1518.808	9.052	167.8	0.00596	13.0	5.0	5.0
1205.837	8.483	142.1	0.00704	18.0	10.0	5.0
674.309	6.989	96.5	0.01036	38.0	30.0	5.0
295.126	4.768	61.9	0.01615	108.0	100.0	5.0
129.875	2.284	56.9	0.01758	308.0	300.0	5.0
63.439	1.116	56.9	0.01759	508.0	500.0	5.0
10.587	0.186	56.9	0.01759	1008.0	1000.0	5.0
IODINE RESIDENCE TIME IN BODY=16						
1664.963	9.790	170.1	0.00588	16.0	0.0	5.0
1628.676	9.704	167.8	0.00596	16.5	0.5	5.0
1594.041	9.621	165.7	0.00604	17.0	1.0	5.0
1529.262	9.466	161.6	0.00619	18.0	2.0	5.0
1364.287	9.052	150.7	0.00663	21.0	5.0	5.0
1158.311	8.483	136.5	0.00732	26.0	10.0	5.0
731.531	6.989	104.7	0.00955	46.0	30.0	5.0
356.034	4.768	74.7	0.01339	116.0	100.0	5.0
160.048	2.284	70.1	0.01427	316.0	300.0	5.0
78.183	1.116	70.1	0.01427	516.0	500.0	5.0
13.047	0.186	70.1	0.01427	1016.0	1000.0	5.0
IODINE RESIDENCE TIME IN BODY=24						
1336.722	9.790	136.5	0.00732	24.0	0.0	5.0
1315.625	9.704	135.6	0.00738	24.5	0.5	5.0
1295.207	9.621	134.6	0.00743	25.0	1.0	5.0
1256.281	9.466	132.7	0.00753	26.0	2.0	5.0
1132.834	9.052	127.4	0.00785	29.0	5.0	5.0
1015.010	8.483	119.6	0.00836	34.0	10.0	5.0
695.674	6.989	99.5	0.01005	54.0	30.0	5.0
368.868	4.768	77.4	0.01292	124.0	100.0	5.0
168.675	2.284	73.9	0.01354	324.0	300.0	5.0
82.401	1.116	73.8	0.01354	524.0	500.0	5.0
13.751	0.186	73.8	0.01354	1024.0	1000.0	5.0
IODINE RESIDENCE TIME IN BODY=48						
798.213	9.790	81.5	0.01227	48.0	0.0	5.0
791.458	9.704	81.6	0.01226	48.5	0.5	5.0
784.828	9.621	81.6	0.01226	49.0	1.0	5.0
771.932	9.466	81.6	0.01226	50.0	2.0	5.0
735.928	9.052	81.3	0.01230	53.0	5.0	5.0
683.621	8.483	80.6	0.01241	58.0	10.0	5.0
539.030	6.989	77.1	0.01297	78.0	30.0	5.0
341.068	4.768	71.5	0.01398	148.0	100.0	5.0
161.238	2.284	70.6	0.01416	348.0	300.0	5.0
78.775	1.116	70.6	0.01416	548.0	500.0	5.0
13.146	0.186	70.6	0.01416	1048.0	1000.0	5.0

1322 290

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=96						
452.205	9.790	46.2	0.02165	96.0	0.0	5.0
450.483	9.704	46.4	0.02154	96.5	0.5	5.0
448.778	9.621	46.6	0.02144	97.0	1.0	5.0
445.424	9.466	47.1	0.02125	98.0	2.0	5.0
435.771	9.052	48.1	0.02077	101.0	5.0	5.0
420.929	8.483	49.6	0.02015	106.0	10.0	5.0
373.363	6.989	53.4	0.01872	126.0	30.0	5.0
275.117	4.768	57.7	0.01733	196.0	100.0	5.0
133.350	2.284	58.4	0.01713	396.0	300.0	5.0
65.154	1.116	58.4	0.01713	596.0	500.0	5.0
10.873	0.186	58.4	0.01713	1096.0	1000.0	5.0
IODINE RESIDENCE TIME IN BODY=300						
171.521	9.790	17.5	0.05708	300.0	0.0	5.0
171.214	9.704	17.6	0.05668	300.5	0.5	5.0
170.906	9.621	17.8	0.05630	301.0	1.0	5.0
170.294	9.466	18.0	0.05558	302.0	2.0	5.0
168.469	9.052	18.6	0.05373	305.0	5.0	5.0
165.472	8.483	19.5	0.05127	310.0	10.0	5.0
154.017	6.989	22.0	0.04538	330.0	30.0	5.0
119.852	4.768	25.1	0.03978	400.0	100.0	5.0
58.559	2.284	25.6	0.03900	600.0	300.0	5.0
28.612	1.116	25.6	0.03900	800.0	500.0	5.0
4.775	0.186	25.6	0.03900	1300.0	1000.0	5.0
TIME IN CLOUD= 10						
IODINE RESIDENCE TIME IN BODY=2						
7301.425	18.842	387.5	0.00258	2.0	0.0	10.0
6475.656	18.693	346.4	0.00289	2.5	0.5	10.0
5832.608	18.549	314.4	0.00318	3.0	1.0	10.0
4906.493	18.275	268.5	0.00372	4.0	2.0	10.0
3457.231	17.535	197.2	0.00507	7.0	5.0	10.0
2423.290	16.501	146.9	0.00681	12.0	10.0	10.0
1170.168	13.715	85.3	0.01172	32.0	30.0	10.0
464.272	9.438	49.2	0.02033	102.0	100.0	10.0
200.413	4.527	44.3	0.02259	302.0	300.0	10.0
97.889	2.212	44.3	0.02260	502.0	500.0	10.0
16.335	0.369	44.3	0.02260	1002.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=4						
5818.834	18.842	308.8	0.00324	4.0	0.0	10.0
5411.862	18.693	289.5	0.00345	4.5	0.5	10.0
5069.188	18.549	273.3	0.00366	5.0	1.0	10.0
4521.674	18.275	247.4	0.00404	6.0	2.0	10.0
3484.125	17.535	198.7	0.00503	9.0	5.0	10.0
2583.849	16.501	156.6	0.00639	14.0	10.0	10.0
1321.676	13.715	96.4	0.01038	34.0	30.0	10.0
542.975	9.438	57.5	0.01738	104.0	100.0	10.0
235.979	4.527	52.1	0.01918	304.0	300.0	10.0
115.263	2.212	52.1	0.01919	504.0	500.0	10.0
19.235	0.369	52.1	0.01919	1004.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=8						
4610.252	18.842	244.7	0.00409	8.0	0.0	10.0
4432.020	18.693	237.1	0.00422	8.5	0.5	10.0
4269.200	18.549	230.2	0.00434	9.0	1.0	10.0
3981.835	18.275	217.9	0.00459	10.0	2.0	10.0
3333.230	17.535	190.1	0.00526	13.0	5.0	10.0
2646.372	16.501	160.4	0.00624	18.0	10.0	10.0
1479.863	13.715	107.9	0.00927	38.0	30.0	10.0
647.695	9.438	68.6	0.01457	108.0	100.0	10.0
285.029	4.527	63.0	0.01588	308.0	300.0	10.0
139.227	2.212	62.9	0.01589	508.0	500.0	10.0
23.234	0.369	62.9	0.01589	1008.0	1000.0	10.0

1322 291

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=16						
3432.525	18.842	182.2	0.00549	16.0	0.0	10.0
3357.714	18.693	179.6	0.00557	16.5	0.5	10.0
3286.310	18.549	177.2	0.00564	17.0	1.0	10.0
3152.760	18.275	172.5	0.00580	18.0	2.0	10.0
2812.644	17.535	160.4	0.00623	21.0	5.0	10.0
2387.999	16.501	144.7	0.00691	26.0	10.0	10.0
1508.140	13.715	110.0	0.00909	46.0	30.0	10.0
734.008	9.438	77.8	0.01286	116.0	100.0	10.0
329.959	4.527	72.9	0.01372	316.0	300.0	10.0
161.183	2.212	72.9	0.01372	516.0	500.0	10.0
26.898	0.369	72.9	0.01372	1016.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=24						
2702.817	18.842	143.4	0.00697	24.0	0.0	10.0
2660.161	18.693	142.3	0.00703	24.5	0.5	10.0
2618.877	18.549	141.2	0.00708	25.0	1.0	10.0
2540.168	18.275	139.0	0.00719	26.0	2.0	10.0
2331.001	17.535	132.9	0.00752	[illegible].0	5.0	10.0
2052.325	16.501	124.4	0.00804	[illegible]4.0	10.0	10.0
1406.636	13.715	102.6	0.00975	54.0	30.0	10.0
745.841	9.438	79.0	0.01265	124.0	100.0	10.0
341.056	4.527	75.3	0.01327	324.0	300.0	10.0
166.612	2.212	75.3	0.01328	524.0	500.0	10.0
27.804	0.369	75.3	0.01328	1024.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=48						
1595.914	18.842	84.7	0.01181	48.0	0.0	10.0
15[illegible]2.408	18.693	84.7	0.01181	48.5	0.5	10.0
1569.153	18.549	84.6	0.01182	49.0	1.0	10.0
1543.369	18.275	84.5	0.01184	50.0	2.0	10.0
1471.383	17.535	83.9	0.01192	53.0	5.0	10.0
1366.804	16.501	82.8	0.01207	58.0	10.0	10.0
1077.714	13.715	78.6	0.01273	78.0	30.0	10.0
681.917	9.438	72.3	0.01384	148.0	100.0	10.0
322.372	4.527	71.2	0.01404	348.0	300.0	10.0
157.499	2.212	71.2	0.01404	548.0	500.0	10.0
26.283	0.369	71.2	0.01404	1048.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=96						
903.391	18.842	47.9	0.02086	96.0	0.0	10.0
899.949	18.693	48.1	0.02077	96.5	0.5	10.0
896.545	18.549	48.3	0.02069	97.0	1.0	10.0
889.843	18.275	48.7	0.02054	98.0	2.0	10.0
870.559	17.535	49.6	0.02014	101.0	5.0	10.0
840.908	16.501	51.0	0.01962	106.0	10.0	10.0
745.885	13.715	54.4	0.01839	126.0	30.0	10.0
549.614	9.438	58.2	0.01717	196.0	100.0	10.0
266.400	4.527	58.8	0.01699	396.0	300.0	10.0
1[illegible]0.162	2.212	58.8	0.01699	596.0	500.0	10.0
21.721	0.369	58.8	0.01699	1096.0	1000.0	10.0
IODINE RESIDENCE TIME IN BODY=300						
342.655	18.842	18.2	0.05499	300.0	0.0	10.0
342.040	18.693	18.3	0.05465	300.5	0.5	10.0
341.426	18.549	18.4	0.05433	301.0	1.0	10.0
340.202	18.275	18.6	0.05372	302.0	2.0	10.0
336.557	17.535	19.2	0.05210	305.0	5.0	10.0
330.570	16.501	20.0	0.04992	310.0	10.0	10.0
307.685	13.715	22.4	0.04458	330.0	30.0	10.0
239.433	9.438	25.4	0.03942	400.0	100.0	10.0
11[illegible].986	4.527	25.8	0.03870	600.0	300.0	10.0
57.160	2.212	25.8	0.03870	800.0	500.0	10.0
9.539	0.369	25.8	0.03870	1300.0	1000.0	10.0

1322 292

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
TIME IN CLOUD= 18						
IODINE RESIDENCE TIME IN BODY=2						
16612.146	32.186	516.1	0.00194	2.0	0.[illegible]	18.0
14733.364	31.961	461.0	0.00217	2.5	[illegible]	[illegible]8.0
13270.305	31.742	418.1	0.00239	3.0	1.0	18.0
11163.216	31.321	356.4	0.00281	4[illegible]	2.0	18.0
7865.866	30.170	260.7	0.00384	[illegible].0	5.0	18.0
5513.450	28.534	193.2	0.00518	12.0	10.0	18.0
2662.357	24.000	110.9	0.00901	32.0	30.0	18.0
1056.308	16.717	63.2	0.01583	102.0	100.0	18.0
455.979	8.034	56.8	0.01762	30[illegible].0	300.0	18.0
222.717	3.925	56.7	0.01762	50[illegible].0	500.0	18.0
37.166	0.655	56.7	0.01762	1002.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=4						
12335.108	32.186	383.2	0.00261	4.0	0.0	18.0
11472.385	31.961	359.0	0.00279	4.5	0.5	18.0
10745.964	31.742	338.5	0.00295	5.0	1.0	18.0
9585.313	31.321	306.0	0.00327	6.0	2.0	18.0
7385.855	30.170	244.8	0.00408	9.0	5.0	18.0
5477.395	28.534	192.0	0.00521	14.0	10.0	18.0
2801.768	24.000	116.7	0.00857	34.0	30.0	18.0
1151.031	16.717	68.9	0.01452	104.0	100.0	18.0
500.241	8.034	62.3	0.01606	304.0	300.0	18.0
244.341	3.925	62.2	0.01606	504.0	500.0	18.0
40.775	0.655	62.2	0.01606	1004.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=8						
9063.279	32.186	281.6	0.00355	8.0	[illegible].0	18.0
8712.893	31.961	272.6	0.00367	8.5	0.5	18.[illegible]
8392.806	31.742	264.4	0.00378	9.0	1.0	18.0
7827.876	31.321	249.9	0.00400	10.0	2.0	18.0
6552.786	30.170	217.2	0.00460	13.0	5.0	18.0
5202.494	28.534	182.3	0.00548	18.0	10.0	18.0
2909.258	24.000	121.2	0.00825	38.0	30.0	18.0
1273.301	16.717	76.2	0.01313	108.0	100.[illegible]	18.0
560.337	8.034	69.7	0.01434	308.0	300.0	18.0
273.705	3.925	69.7	0.01434	508.0	500.0	18.0
45.675	0.655	69.7	0.01434	1008.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=16						
6367.910	32.1[illegible]	197.8	0.00505	16.0	0.0	18.0
6229.122	31.961	194.9	0.00513	16.5	0.5	18.0
6096.656	31.742	192.1	0.00521	17.0	1.0	18.0
5848.8[illegible]9	31.321	186.7	0.00535	18.0	2.0	18.0
52[illegible]7.926	30.170	172.9	0.00578	21.0	5.0	18.0
4430.139	28.534	155.3	0.00644	26.0	10.0	18.0
2797.853	24.000	116.6	0.00858	46.0	30.0	18.0
1361.709	16.717	81.5	0.01[illegible]	116.0	100.0	18.0
612.130	8.034	76.2	0.01312	316.0	300.0	18.0
299.022	3.925	76.2	0.01313	516.0	500.0	18.0
49.900	0.655	76.2	0.01313	1016.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=24						
4917.356	32.186	152.8	0.00655	24.0	0.0	18.0
4839.749	31.961	151.4	0.00660	24.5	0.5	18.0
4764.639	31.742	150.1	0.00666	25.0	1.0	18.0
4621.441	31.321	14[illegible].6	0.00678	26.0	2.0	18.0
4240.8[illegible]	30.170	140.6	0.00711	29.0	5.0	18.[illegible]
3733.8[illegible]	28.534	130.9	0.00764	34.0	10.0	18.0
2559.155	24.000	106.6	0.00938	54.0	30.0	18.0
1356.943	16.717	81.2	0.01232	124.0	100.0	18.0
620.499	8.034	77.2	0.01295	324.0	[illegible]00.0	18.0
303.125	3.925	[illegible]7.[illegible]	0.01295	524.0	500.0	18.0
50.584	0.655	77.2	0.01295	102[illegible]	1000.0	18.0

1322 293

CPM	H(inf)	CPM / H(inf)	H(inf) / CPM	t_2	t	dt
IODINE RESIDENCE TIME IN BODY=48						
2869.889	32.186	89.2	0.0112[illegible]	48.0	0.0	18.0
2845.602	31.961	89.0	0.01123	48.5	0.5	18.0
2821.766	31.742	88.9	0.01125	49.0	1.0	18.0
2775.399	31.321	88.6	0.01129	50.0	2.0	18.0
2645.949	30.170	87.7	0.01140	53.0	5.0	18.0
2457.886	28.534	86.1	0.01161	58.0	10.0	18.0
1938.024	24.000	80.8	0.01238	78.0	30.0	18.0
1226.273	16.717	73.4	0.01363	148.0	100.0	18.0
579.712	8.034	72.2	0.01386	348.0	300.0	18.0
283.226	3.925	72.2	0.01386	548.0	500.0	18.0
47.264	0.655	72.2	0.01386	1048.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=96						
1623.169	32.186	50.4	0.01983	96.0	0.0	18.0
1616.986	31.961	50.6	0.01977	96.5	0.5	18.0
1610.869	31.742	50.7	0.01970	97.0	1.0	18.0
1598.828	31.321	51.0	0.01959	98.0	2.0	18.0
1564.179	30.170	51.8	0.01929	101.0	5.0	18.0
1510.904	28.534	53.0	0.01889	106.0	10.0	18.0
1340.171	24.000	55.8	0.01[illegible]91	126.0	30.0	18.0
987.521	16.717	59.1	0.[illegible]93	196.0	100.0	18.0
478.655	8.034	59.6	[illegible]678	396.0	300.0	18.0
233.868	3.925	59.6	[illegible]1678	596.0	500.0	18.0
39.027	0.655	59.[illegible]	0.01678	1096.0	1000.0	18.0
IODINE RESIDENCE TIME IN BODY=300						
615.663	32.186	19.1	0.05228	300.0	0.0	18.0
614.558	31.961	19.2	0.05201	300.5	0.5	18.0
613.455	31.742	19.3	0.05174	301.0	1.0	18.0
611.256	31.321	19.5	0.05124	302.0	2.0	18.0
604.707	30.170	20.0	0.04989	305.0	5.0	18.0
593.950	28.534	20.8	0.04804	310.0	10.0	18.0
552.831	24.000	23.0	0.04341	330.0	30.0	18.0
430.201	16.717	25.7	0.03886	400.0	100.0	18.0
210.194	8.034	26.2	0.03822	600.0	300.0	18.0
102.702	3.925	26.2	0.03822	800.0	500.0	18.0
17.139	0.655	26.2	0.03822	1300.0	1000.0	18.0

1322 294

Distribution List

Copies	Addresses
185	Category RE
50	Detection & Countermeasures Division DCPA, The Pentagon Washington, DC 20301
15	Mr. E. Williams, Chief RADEF Instrumentation Building 22 Paulding Street, S.E. Washington Navy Yard Washington, DC 20374
1	Mr. Phillip Reed Nuclear Regulatory Commission Office of Nuclear Regulatory Research Division of Safeguards, Fuel Cycle, & Environmental Research Health & Environmental Research Branch Washington, DC 20555
1	Mr. H. Collins Office of State Programs U.S. Nuclear Regulatory Commission Washington, DC 20555
1	Mr. R. Defayette Office of State Programs U.S. Nuclear Regulatory Commission Washington, DC 20555
1	Mr. S. Block U.S. Nuclear Regulatory Commission Mail Stop 545 (EED) Washington, DC 20555
1	Mr. G. Szeto Division of Naval Reactors H-404 U.S. Nuclear Regulatory Commission Washington, DC 20555
1	Mr. James A. Martin, Jr. (242) U.S. Nuclear Regulatory Commission Washington, DC 20555

1322 295

Distribution List

Copies	Addresses
1	Ms. Monica Grooms Allied General Nuclear Services P.O. Box 847 Barnwell, SC 29812 ID No. 77-309
1	Mr. E. Vallario U.S. Department of Energy Division of Operational Safety Washington, DC 20545
1	Mr. Winston Ward Health & Environmental Protection General Electric Company Box 1072 Schenectady, NY 12301
1	Mr. A. Heubner Radiation Unit State Department of Environmental Protection State Office Building Hartford, CT 06115
1	Mr. Gale Schmidt Standards & Regulatory Branch Department of Health, Education & Welfare Bureau of Radiological Health HFX 460 5600 Fishers Lane Rockville, MD 20852
1	Mr. Gene Reimer Calvert Cliffs Nuclear Power Plant Lusby, MD 20657
1	Mr. Dale Donaldson Office of Inspection & Enforcement U.S. Nuclear Regulatory Commission 631 Park Avenue King of Prussia, PA 19406
1	Mr. J. K. Soldat Safety & Environmental Analysis Section Energy Systems Department Battelle Northwest Labs. Richland, WA 99352

Distribution List

Copies	Addresses
1	Mr. H. Mark Blauer Department of Radiation Health Graduation School of Public Health University of Pittsburg Pittsburg, PA 15213
2	Ms. Mary Evers Technical Library TVA Muscle Shoals, AL 35660
1	Dr. D. Schutz Teledyne Isotopes 50 Van Buren Avenue Westwood, NJ 07675
1	Mr. K. Murphy U.S Nuclear Regulatory Commission Accident Analysis Branch Washington, DC 20555
1	Mr. J. Stern Metropolitan Vacuum Cleaner, Inc. 19 Wayne Avenue Suffern, NY 10901
1	Mr. Fred Haynes 111 S. Fourth Avenue Highland Park, NJ 08904
1	Mr. Aubrey V. Godwin Division of Radiological Health Department of Public Health State Office Building Montgomery, AL 36130
1	Mr. Sherwood Davies Bureau of Radiological Health State of New York, Department of Health Tower Building, Empire State Plaza Albany, NY 12237
1	Mr. J. Beer, P24-103 Consumers Power Company 212 W. Michigan Avenue Jackson, MI 49201

1322 297

<u>Distribution List</u>

Copies	Addresses
1	Mr. Lysle Schwendiman Particulate & Gaseous Waste Research Atmospheric Sciences Battelle Northwest Labs. Richland, WA 99352
1	Mr. Michael Miele Health Physics Group Shoreham Nuclear Power Station P.O. Box 628 Wading River, NY 11792
1	Dr. Reginald C. Rodgers Generation Technical Services Northeast Utilities P.O. Box 270 Hartford, CT 06101
10	BNL Distribution
50	File Copies
1	Dr. M. J. Kabot Ontario Hydro Central Health Physics Services Pickering Generating Station Box 160 Pickering, Ontario, Canada
1	Mr. Carl O. Widell AB ATOMENERGI Studsvik S-61101 Nyköping Sweden
1	Mr. Otokar Vojtisek The Hygienic Center of the City of Prague Department of Radiation Hygiene Rytirska' 12, 11001 Prague 1 Czechoslovakia
1	Mr. J. P. Deworm Health Physics Department S.C.K./C.E.N. Boeretang 200 B-2400 MOL (Belgium)

1322 298

Distribution List

Copies	Addresses
1	Mr. Denis Aliaga-Kelly Nuclear Enterprises Ltd. Sighthill, Edinburgh EH 11 4EY, Scotland
1	Mr. D. S. Deshingkar Bhabha Atomic Research Centre Air Cleaning Engineering Research S-71 South Site, Trombay Bombay 400 085, India
1	Dr. A. Tietze Techischer Uberwachungs Verein Rheinland Institut f. Unfallforschung An Grauen Stein Konstantin Wille Strasse 1 D-500 Köln 91 Federal Republic of Germany
1	Dr. I. Feher Central Research Institute for Physics H-1525 Budapest POB 49 Hungary
1	Dr. J. G. Wilhelm Nuclear Research Center Karlsruhe Laboratory for Filter Technology 75 Karlsruhe 1, Postfach 3640 Karsruhe, Federal Republic of Germany

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U.S. NUCLEAR REGULATORY
COMMISSION

U.S. MAIL

POOR ORIGINAL

120555031837 2 ANRE
US NRC
SECY PUBLIC DOCUMENT ROOM
BRANCH CHIEF
HST LOBBY
WASHINGTON DC 20555

1322 300

P-016