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MILK TO AIR RATIOS FOR
IODINE-131 CONCENTRATIONS (PROJECT ROVER)

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MILK TO AIR RATIOS FOR ^{131}I CONCENTRATIONS
(PROJECT ROVER)

Public Health Service environmental surveillance results from Project Rover reactor tests at NRDS (1962 - 1967), Jackass Flats, Nevada, were evaluated to determine the following parameters for predicting ^{131}I concentrations in milk:

1. Peak concentration in vegetation to integrated air concentration - $\text{pCi/kg}:\text{pCi-sec/m}^3$
2. Peak concentration in milk to peak concentration on vegetation - $\text{pCi/l}:\text{pCi/kg}$
3. Peak concentration in milk to integrated air concentration - $\text{pCi/l}:\text{pCi-sec/m}^3$

The parameters are described by a log normal distribution with geometric mean ($\bar{X}_g$) and geometric standard deviation (S_g). Thus both the most probable value and the variation of the value is described.

The value obtained for milk to air (ratio three and the product of one and two above) was 4×10^{-4} pCi/l: pCi-sec/m³) with an S_g of three. The use of a log normal distribution, in addition to being a reasonable fit of the data, allows a simple propagation of errors for the products of parameters.

MILK TO AIR RATIOS FOR ^{131}I CONCENTRATIONS
(PROJECT ROVER)

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INTRODUCTION

Project Rover, the United States Program to develop a nuclear powered rocket, is a joint program of the Atomic Energy Commission (AEC) and National Aeronautics and Space Administration (NASA). It is administered by the Space Nuclear Propulsion Office (SNPO). Ground tests for this program are conducted at the Nuclear Rocket Development Station (NRDS), Jackass Flats, Nevada (adjacent to the Nevada Test Site). The radiation protection program for these tests includes dose predictions for both the normal and the accident case and a detailed environmental surveillance program. Under a memorandum of agreement between the AEC and the Public Health Service (PHS), the PHS is responsible for the off-site radiological safety and surveillance program

for the Nevada Test Site and NRDS.

OBJECTIVES AND METHODS

The objective of this paper is to determine empirical parameters which may be used in the prediction program for radioiodine concentrations in milk resulting from NRDS tests. Data from the PHS off-site surveillance program, for Project Rover tests, was used in the analysis. The results are limited to concentrations for the time of the year when cows are on fresh feed, i.e., milk concentrations resulting during winter months of the year when cows are on stored feed are not considered.

It is recognized that the quantity of results is limited. This is caused by several factors including:

- a. The objective of reactor tests is reactor testing and evaluation, not environmental surveillance data.
- b. Tests are often held during the winter.
- c. Effluent releases have generally been relatively low resulting in a limited number of locations where radioiodine is found in milk.

- d. Due to the uncertainties in predicting effluent trajectory, it is difficult to get sampling arrays ideally positioned.
- e. The population and milk cow density is fairly low around NTS.

The results are related to acute versus chronic deposition of radioiodine effluent release and cloud passage times.

Specifically this study is to determine the "transport ratio" for ^{131}I air to milk concentrations. Both the mean for the value and its statistical variation are of interest.

The following concentration ratios were determined from the surveillance data:

1. ^{131}I peak in milk: ^{131}I integrated air concentration
2. ^{131}I peak in milk: ^{131}I vegetation - cow feed
3. ^{131}I and ^{133}I vegetation - cow feed: ^{131}I and ^{133}I

integrated air concentration

4. ^{131}I peak in milk: ^{131}I vegetation - natural
5. ^{131}I peak in milk: ^{131}I vegetation - all vegetation
6. ^{131}I and ^{133}I natural vegetation: ^{131}I and ^{133}I
integrated air concentration
7. ^{131}I and ^{133}I total vegetation: ^{131}I and ^{133}I
integrated air concentration

All the ratios referenced to milk are based on fresh feed (growing season) conditions and ^{131}I concentrations. The ratios for ^{133}I in milk and other media were not used. They are not directly related to ^{131}I "milk ratios" because of the shorter half-life of ^{133}I and the build-up phenomenon associated with concentrations in milk resulting from vegetation and air ratios.

The ratio of concern is the ^{131}I milk to air ratio. The other ratios were determined as supporting information.

The question arises; what type of vegetation sample

should we use, i.e., natural,* cow feed, or both?
Thus, all three of these ratios were determined
for both milk to vegetation and vegetation to air.

The analyses of the data is based on a log normal distribution defined by the geometric mean and geometric standard deviation.** The log normal distribution arises from a theory of variances or errors combined by a multiplication process where the normal distribution arises from a theory of elemental errors combined by addition.¹

*Generally greasewood or sagebrush.

**The geometric mean $\bar{X}_g$ is defined as the nth root of the product of n numbers or the antilog of the average of the log of numbers. It denotes the result at which the probability is such that 50% of the results will be above or below. It is not equal to the arithmetic mean. The geometric standard deviation S_g may be defined as the 84.1% probability value divided by the 50% probability value. It is also equal to the antilog of the standard deviation of the log of the numbers.

RESULTS

Table I Table I gives a list of past reactor tests. Those yielding results which were useable in this analysis are so indicated.

Table II The ratios and the event from which the results were obtained are indicated in Appendix A. Table II gives the $\bar{X}_g$ and S_g of the ratios (indicated under objectives). Ratio eight, from Table II, is a product of ratios two and three and is analogous to ratio one but is based on additional results.

A problem in the evaluation of data of this type, when the number of results are limited, is the proper perspective of quality and quantity of data. Thus, the initial analysis dealt with the semblance of the various ratios, that is:

1. Relationship of ratios of ^{131}I concentrations for vegetation to air and ^{133}I ratios for vegetation to air. A plot of the two sets of data showed essentially no difference between these ratios. Thus, the results were composited.
2. The relationships of the vegetation to air ratio

for natural and cow feed types of vegetation differed by a factor of about 1.4. Therefore, the ratios using natural vegetation were not directly used in this analysis and are only given for comparison.

Figure I

Figure I indicates the log normal frequency distribution for the milk to air ratio ($\text{pCi/l}:\text{pCi-sec/m}^3$). The points are plots of the data from Appendix A by interval, i.e., less than 2, 3, $4 \times 10^{-4} \text{ m}^3/\text{l-sec}$, etc. The indicated line is based on the calculated $\bar{X}_g$ and S_g . The solid line presents the results of the ^{131}I milk to air ratio (ratio one from Table II). The dotted line results from the product of the ratios for milk to feed and feed to air (ratio eight in Table II). This distribution is defined by:

1. The geometric mean for the new distribution is the antilog of the sum of the logs of the geometric means, i.e., their product.
2. The geometric standard deviation is the antilog of the square root of the sum of the squares of the standard deviations of the log normal distributions.

The analytical techniques for sample analysis are discussed in Appendix B.

DISCUSSION

The vegetation ratios should not be used separately from the other information in this report. In our surveillance program vegetation samples are used primarily to indicate areas of cloud passage. The vegetation samples are not quantitated absolutely, rather the emphasis is on relative radionuclide concentrations. The true quantities present appear to be a factor of about 1.5 times the value obtained by our routine analysis (see Appendix B). When milk to vegetation and vegetation to air ratios are used together, the vegetation values cancel, but if used separately, the quantitation of the vegetation must be considered.

The vegetation results in this report and our surveillance program are quantitated on the basis of mass not area, i.e., pCi/kg not pCi/m². This is done primarily because of ease of analysis, but also has a number of advantages:

1. Vegetation can be collected in the field and taken

to the lab to be weighed. An area determination must be made in the field.

2. Cows eat a mass of vegetation, not unit area.
3. The deposition (velocity (V_g) results in values of radioactivity per unit area, but if the density of vegetation ground cover varies, proper interpretation becomes difficult.
Is the unit area horizontal area or plant area, how do you measure it, etc?

If the ratio $\text{pCi/g}:\text{pCi-sec/m}^3$ is used, a parameter (V_m) with the units $\text{m}^3/\text{g-sec}$ is obtained.* This is equivalent to the "deposition velocity" times the ground density of vegetation ($\text{m/sec} \times \text{m}^2/\text{g} = \text{m}^3/\text{g-sec}$). Considering the problems that have resulted from the use of the term deposition velocity (sometimes incorrectly related to settling velocity) it would seem reasonable to coin a new term; possibly "mass retention parameter."

*This unit has also been used in the Controlled Environmental Radioiodine Tests (CERT).²

As has been previously indicated, the results are limited in quantity. More information could have been obtained by distance extrapolation of air results, but it was felt that this would increase rather than decrease uncertainties. The results used in this report were collected over a long period of time with the prime motive of health and safety. The results encompass a large number of variables such as meteorological conditions (varying wind speed and lapse rate, precipitation, etc.)*, possible variations in the particulate to gaseous ratio of the effluent, biological variability, chemical state of radioiodine, etc. It would appear, especially from the scientific viewpoint, to be advantageous to separate out many of these variables. But, there is not adequate data to do that in this study. Also, the point can be made that these variables are generally unknown prior to and often after

*Variations in deposition due to rainout and/or washout may not be fully covered by the reported data. But, rainfall did occur during the Phoebus 1A and NRX A4, EP-1V A events, but its effect is difficult to assess. The exact time and area of rainfall are not known.

an event; thus, they should be encompassed in a prediction. It is felt that this analysis "brackets" these variables.

A Chi-squared test (95% confidence level) was used to check the fit of the line in Figure I (direct milk to air ratio) to the actual data. The test indicated an acceptable fit.

CONCLUSIONS

Consideration of the data results in an estimated distribution for the milk to air ratio with $\bar{X}_g = 4 \times 10^{-4}$ pCi/1 pcr pCi-sec/m³ and $S_g = 3$. The value of $\bar{X}_g$ comes from rounding off the results from Figure I, where a value of S_g of 3 is admittedly conservative (2.5 appears more reasonable). But, based on the various S_g 's in Table II and the limited amount of data, the value 3 appears to be prudent.

Of prime concern is the concept that the ratios are described by a distribution rather than a single value. It is well to note that the reported variation includes

the variation inherent in sample collection and analysis as well as the variation from environmental transport. It should be reiterated that the amount of data available was minimal for an analysis of this type. I feel the results are reasonable, but they are for a specific environment and type of source and are susceptible to change with additional data and analysis.

REFERENCES

1. Aitchison, J., and Brown, J. A. C., The Log-Normal Distribution, Cambridge, 1963.
2. Hawley, C. A., Editor, "Controlled Environmental Radioiodine Tests At the National Reactor Testing Station, 1965 Progress Report," IDO-12047, February, 1966.

TABLE I

REACTOR EVENTS USED IN ANALYSIS

<u>Event</u>	<u>Date</u>	<u>Used</u>	<u>Comment</u>
KIWI-A	5/59-6/59		Inadequate results
KIWI-A' & A3	6/60-7/60		Inadequate results
KIWI-B-1A	12/7/61		Inadequate results
KIWI-B-1B	9/1/62	X	
KIWI-B-4A	11/30/62		Inadequate results
KIWI-B-4D	5/13/64	X	
KIWI-B-4E, EP-V	8/28/64		Inadequate results
KIWI-B-4E, EP-VI	9/10/64	X	
NRX-A2, EP-IV	9/24/64	X	
NRX-A2, EP-V	10/15/64		Inadequate results
KIWI-TNT	1/12/65	X	
NRX-A3, EP-IV	4/23/65		Inadequate results
NRX-A3, EP-V	5/20/65	X	
NRX-A3, EP-VI	5/28/65		Interference from foreign test, 5/14
PHOEBUS-1A, EP-IV	6/25/65	X	
NRX-A4, EP-IV	3/16/66	X	
NRX-A4, EP-IV A	3/25/66	X	
NRX-A5 EP-III	6/8/66	X	
NRX-A5, EP-IV	6/23/66	X	

TABLE I (CONT'D)

<u>Event</u>	<u>Date</u>	<u>Used</u>	<u>Comment</u>
PHOEBUS-1B, EP-III	2/10/66		Inadequate results
PHOEBUS-1B, EP-IV	2/23/66	X	

TABLE II

RADIOIODINE MILK, VEGETATION TO AIR CONCENTRATION RATIOS

Ratio	No. of Results	Units	Geometric Mean - $\bar{X}_g$	Geometric Standard Deviation S_g
1. ^{131}I Milk : Air	6	pCi/l : pCi-sec/m ³	3.72×10^{-4}	2.0
2. ^{131}I Milk : Feed	12	pCi/l : pCi/kg	0.144	1.8
3. ^{131}I and ^{133}I Feed : Air	17	pCi/kg : pCi-sec/m ³	2.20×10^{-3}	2.5
4. ^{131}I Milk : Nat. Vegt.	7	pCi/l : pCi/kg	0.235	1.8
5. ^{131}I Milk : Total Vegt.	19	pCi/l : pCi/kg	0.172	1.8
6. ^{131}I and ^{133}I Nat. Vegt : Air	55	pCi/kg : pCi-sec/m ³	2.91×10^{-3}	3.5
7. ^{131}I or ^{133}I Total Vegt : Air	72	pCi/kg : pCi-sec/m ³	2.70×10^{-3}	3.0
8. Product (Milk : Feed) x (Feed : Air)		pCi/l : pCi-sec/m ³	3.2×10^{-4}	2.9

NOTE: Vegetation results are for kilograms wet weight.

Note comments in Appendix B as to quantitation of vegetation results.

FIGURE I

Log Normal Probability Plot

^{131}I Peak in Milk : Integrated Air Concentration
(pCi/l : pCi-sec/m³)

———— Calculated direct from Milk : Air

----- Product $\frac{\text{milk}}{\text{vegt}} \times \frac{\text{vegt}}{\text{air}}$

FIGURE 1

APPENDIX A

RATIOS - MILK, VEGETATION, TO AIR

Event	Vegt : Air $\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Vegt. $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	Comment
	131	133	131		131	
KIWI-B1B	1.85			N		
9/62						
KIWI-B4D	12.8	18.0		N		
5/13/64		15.0		N		
		28.0		N		
		12.0		N		
			0.20	N		
			0.58	N		
			0.46	N		
			0.20	N		

APPENDIX A (CONT'D)

Event	Vegt : Air $\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Vegt. $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	Comment
	131	133	131		131	
<hr/>						
KIWI-B4E						
EP-VI	4.43	3.96		N		
9/10/64	5.40	3.37		F		
	7.90	2.96	0.12	F	9.3	
	4.65	1.40	0.20	N		
	6.50		0.13	N		
NRX-A2						
EP-IV	3.97	2.55		F		
9/24/64		2.33		F		
	1.25	0.61		N		

APPENDIX A (CONT'D)

Event	Vegt : Air $\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Vegt. $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$		Comment
	131	133	131		131		
KIWI-TNT		4.66		N			
1/12/65		5.78		N			
		0.22		N			
NRX-A3							
EP-V	1.54			F			
5/20/65	1.4	1.14	0.18	F	2.5		
		5.80		N			
	10.0	11.0		N			
	3.65	4.06		N			
	3.4	4.08		N			
	0.253	0.16		N			
	0.895	0.76		N			

APPENDIX A (CONT'D)

Event	Air : Vent. $\frac{\text{pCi/l} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Vent. $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	Comment
	2'	133	131		131	
PHOEBUS-1A						
EP-IV	2.67		0.13	F	3.4	
6/25/65			0.14	N		
			0.12	F		
			0.11	F	7.2	
	6.40	4.10		F		
	1.40	25.0		N		
	0.55	2.70		N		
	18.0	1.10		N		
NRX-EST/A4						
EP-IV	2.65	9.10		N		No milk-
3/16/66	2.33	1.62		N		cows on stored feed

APPENDIX A (CONT'D)

Event	Veget : Air $\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Veget $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	Comment
	131	133	131		131	
NRX-EST/A4						
EP-IV A			0.24	F		Cows on 9/10
3/25/66			0.07	F		stored feed
	0.35	0.27	0.54	F	1.9	
		4.78		N		
		2.80		F		
		3.78		N		
	2.18			N		
		3.70		N		
NRX-A5						
EP-III	1.56		0.14	F	2.2	
6/18/66						

APPENDIX A (CONT'D)

Event	Vegt : Air		Milk : Vegt	Type	Milk : Air	Comment
	$\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		$\frac{\text{pCi/l}}{\text{pCi/kg}}$	Feed	$\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	
	131	133	131		131	
NRX-A5						
EP-IV	7.5	2.37		N		
6/23/66	11.2	5.00		N		
			0.22	F		
			0.07	F		
			0.11	F		
	3.77	2.58		N		
	7.15	6.12		N		
PHOEBUS-1B						
EP-IV	0.25	0.64		N		
2/23/67	0.75			N		Winter

APPENDIX A (CONT'D)

Event	Vegt : Air $\frac{\text{pCi/kg} \times 10^{-3}}{\text{pCi-sec/m}^3}$		Milk : Vegt $\frac{\text{pCi/l}}{\text{pCi/kg}}$	Type Feed	Milk : Air $\frac{\text{pCi/l} \times 10^{-4}}{\text{pCi-sec/m}^3}$	Comment
	131	133	131		131	
<hr/>						
PHOEBUS-1B						
EP-IV (Cont.)	8.0			N		
	4.80	0.47		N		

N = Natural vegetation

F = Cattle feed, i.e., pasture or green chop

APPENDIX B

ANALYTICAL TECHNIQUES

The samples were analyzed by gamma spectroscopy using a 4 x 4 inch NaI(Tl) crystal and multichannel (200) analyzer. The milk and air results are based on counting efficiencies for standardized geometries. The vegetation samples represent the leafy parts of plants (about 0.5 kilogram) placed in a plastic bag. The plastic bags do not represent a precise geometry, thus an estimated counting efficiency is used.

A study was made where the vegetation samples were compressed into a precise geometry and the result compared to the bulk result.¹ It was noted that the "canned" results were about 1.5 ± 0.28 (95% confidence level) times the bulk results. It was felt that the increased efficiency and reproducibility did not merit the extra sample handling required for compressing the samples (vegetation primarily used as indicator of

¹Bliss, Wayne A., "Iodine-131 on Vegetation : Canned Versus Bulk Counting," Southwestern Radiological Health Laboratory, Intralaboratory Technical Report (ITR-16), July 1967.

cloud passage).

The sensitivity of our counting systems for ^{131}I is about 100 pCi per sample when there is not significant interference from other radioisotopes. The actual sensitivity in pCi per unit sample is dependent on the quantity of sample. The normal sample sizes are:

1. Milk - 3.5 liters
2. Vegetation - 0.5 - 1.0 kilogram
3. Air samples - vary depending on time for cloud passage