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● *Internal Contamination—Decorporation*

STUDIES OF Cs RETENTION IN THE HUMAN BODY RELATED TO BODY PARAMETERS AND PRUSSIAN BLUE ADMINISTRATION

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***Abstract*—Using the *in-vivo* monitoring data from the individuals that suffered internal contamination in the Goiânia accident, a preliminary study on the elimination of Cs from their body was conducted. It was concluded that elimination follows a first-order linear kinetic pattern, both with and without Prussian Blue treatment. Cesium half-lives for both sexes were shown to be influenced mainly by the weight of each individual. In general, Prussian Blue seems to reduce the half-life by 32%. At the time our study was conducted, patients who were under treatment with the drug were receiving 3 g d^{-1}, 6 g d^{-1}, or 10 g d^{-1} of the medication. Our results suggest that there is an optimum dosage for a certain weight range to achieve this reduction in half-life, but one would need more data to statistically prove this assumption.**

INTRODUCTION

IN THE Goiânia accident, 16 d had elapsed between the theft of the Cs source and the discovery by authorities. During this time period, many individuals were exposed to various mixes of external irradiation, skin contamination, and internal contamination, mainly due to ingestion.

Individuals internally contaminated were monitored for the first one and a half months, exclusively by *in-vitro* bioassay; i.e., urine and feces were collected daily and analyzed for their Cs contents. During that time, the external skin contamination was very heavy and could only be removed after several weeks.

In November, a field whole-body counter was set up in Goiânia. By that time, all surface skin contamination had been removed.

A drug known as Prussian Blue (Radiogardase, Heyl Chemischpharmazeutische Fabrik, Berlin, 68% $Fe_4[Fe(CN)_6]_3$) was administered to patients to enhance Cs elimination from the body. In this paper, we have analyzed *in-vivo* data from several patients to evaluate and compare the half-life of ^{137}Cs, with and without Prussian Blue treatment. The possible influence of parameters such as age, height, weight, and activity in the body was evaluated.

METHODS

Individuals were monitored on a regular basis in the whole-body counter installed in Goiânia. The whole-body counter system used is described in the paper by Oliveira et al., entitled "Design and Operation of a Whole-body Monitoring System for the Goiânia Radiation Accident," published in this issue. Our paper presents data collected for the period of 1 y postaccident.

RESULTS AND DISCUSSION

All results presented in this paper are based on *in-vivo* data. The main objective was to analyze the biological half-life of ^{137}Cs in the body, with and without Prussian Blue. The doses of the medication prescribed varied according to age and contamination levels. For children up to 10 y old, the maximum dose administered was 3 g d^{-1}. During the first month after the accident, many patients were given several doses of the drug; e.g., they would receive 1, 1.5, 3, 4, 6, or 10 g d^{-1} during subsequent time periods, varying from patient to patient. These different patterns of drug administration, in addition to the normal fluctuation of excretion data, posed some difficulties in terms of analyzing the differences in effects of the doses given to the same patient and will be the subject of further study. During the *in-vivo* monitoring period, each patient was either on a steady treatment with the drug followed by his release from treatment, or not under medication.

Table 1 presents a summary of data collected from 37 people: 18 females and 19 males. This table shows the half-lives of ^{137}Cs for different dosages of Prussian Blue and biological characteristics, e.g., age, height, and weight. Some individuals never took the medication or stopped taking it before *in-vivo* monitoring started. They are distinguished by only one column in the Prussian Blue region, the 0 g d^{-1}. For all other subjects, data in this column are the half-lives after completion of treatment with the drug.

To compute the half-lives given in Table 1, an exponential regression curve was fitted to the *in-vivo* data.

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Table 1. Biological half-lives for ^{137}Cs whole-body retention as a function of Prussian Blue dosage and biological parameters.

Sex	Age (y)	Weight (kg)	Height (cm)	Half-life (d) Prussian Blue dosage (g d^{-1}) 0	3	6	10
F	2	14	76	26			
F	5	17	104	25			
F	6	20	113	40	26		
F	6	24	121	37			
F	8	22	125	40			
F	10	24	129	34			
F	12	31	136	46			
F	9	31	137	35			
F	36	58	142	53	47		
F	59	60	149	86			
F	29	66	150	58			37
F	29	45	152	39			
F	60	77	153	66			
F	39	42	154	52	47		
F	45	62	160	80			
F	28	67	161	46			
F	25	58	163	104			
F	28	61	166	71			
M	7	21	111	34			
M	7	20	117	31			
M	7	26	118	38	26		
M	8	23	120	45	27		
M	10	27	121	42	30		
M	8	25	128	34	25		
M	14	38	146	43			27
M	13	31	149	49			28
M	14	58	154	51			
M	19	50	157	66			
M	28	69	159	75			61
M	43	73	162	80		62	
M	23	66	164	99			58
M	31	69	165	85		60	
M	33	80	166	106		62	
M	13	55	167	65			42
M	41	63	168	70			52
M	32	61	168	80		56	
M	15	69	174	80	70		

For people treated with Prussian Blue during the monitoring period, two regression curves were obtained, differentiating the half-lives before and after treatment. For the exponential fit of the data, all correlation coefficients (r) were typically 0.98 or better, indicating that ^{137}Cs elimination from the body followed a first-order kinetic model, with and without treatment with Prussian Blue and that the estimation of half-lives was reliable. Without Prussian Blue being administered, it can be seen from Table 1 data that the half-lives for the 10 adult females varied widely, in a range of 39 to 104 d with a mean of 65.5 d.

There was much less variation among the eight adult males, the estimated half-lives ranging from 66 to 106 d, with a mean of 83 d. These half-lives are consistent with data in the literature. Publication No. 30 of the International Commission on Radiological Protection (ICRP) cites biological half-lives varying from 50 to 150 d (ICRP 1979). Leggett et al. have indicated that there is considerable variation in retention times of Cs in humans, this variation being more accentuated for the female, and that there is a good correlation between half-life and total body potassium (Leggett 1986; Leggett et al. 1984).

To evaluate the influence of biological parameters such as height, age, and weight on the elimination of ^{137}Cs for the time period Prussian Blue was not being administered, a stepwise multiple regression analysis for dependent variables was applied (SAS Institute Inc. 1985). Each sex was considered separately. It was concluded that the strongest parameter influencing the half-life was body weight. With this statistical test, it was also concluded that height and age were correlated to the half-lives through their correlation to the weight parameter and are not additional variables besides weight. For the weight parameter, the correlation coefficients for both sexes were significantly different from zero, with $p < 0.0001$ for the males and $p < 0.0005$ for the females. Table 2 presents the correlation coefficient matrix found in this analysis.

The half-life for the period under Prussian Blue treatment, data for all treatment groups analyzed together, was also found strongly correlated to the weight of individuals.

Figures 1, 2, and 3 illustrate the pattern of influence of age, height, and weight parameters on the ^{137}Cs half-life.

The other parameter tested for influence on the half-life was the estimated body burden at the initial time of elimination of ^{137}Cs through its natural kinetics. For people who were medicated with Prussian Blue, the activity of the body at the end of treatment was computed, since natural kinetics were established at that time. For the individuals to whom the drug was never administered, the initial amount in the organism was estimated. For males, the linear correlation coefficient was found to be significantly different from zero ($0.01 < p < 0.025$). For females, the correlation was found to be weaker ($0.05 < p < 0.01$). The correlation coefficients for both sexes were negative, showing an inverse relationship between initial activity and half-life: the larger the initial body burden, the faster the nuclide removal from the organism. However, the influence of this parameter was found to be much weaker than that of body weight. Animal experiments should fol-

Table 2. Matrix of correlation coefficients (r) for various parameters associated with subjects exposed internally to ^{137}Cs in the Goiânia accident.

	Age	Weight	Height	Half-life
Males				
Age	1.00	0.82	0.73	0.77
Weight	0.82	1.00	0.92	0.93
Height	0.73	0.92	1.00	0.85
Half-life	0.77	0.93	0.85	1.00
Females				
Age	1.00	0.86	0.70	0.69
Weight	0.86	1.00	0.84	0.74
Height	0.70	0.84	1.00	0.71
Half-life	0.69	0.74	0.71	1.00

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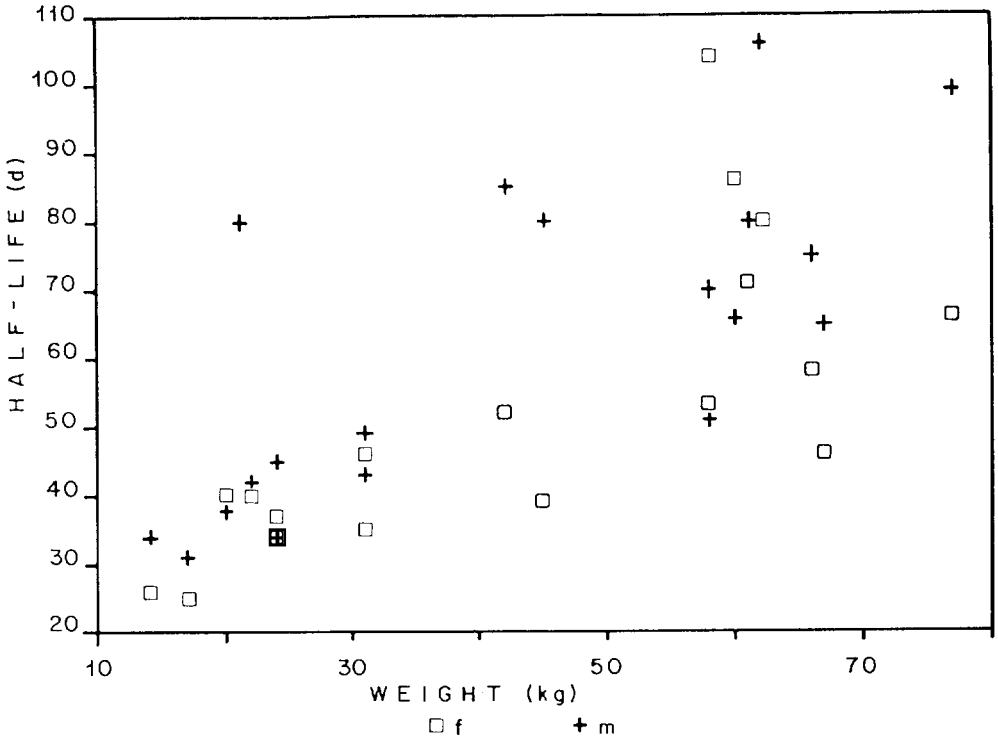

Fig. 1. Whole-body weight vs. half-life of whole-body retention of ^{137}Cs in subjects contaminated with ^{137}Cs from the Goiânia accident.

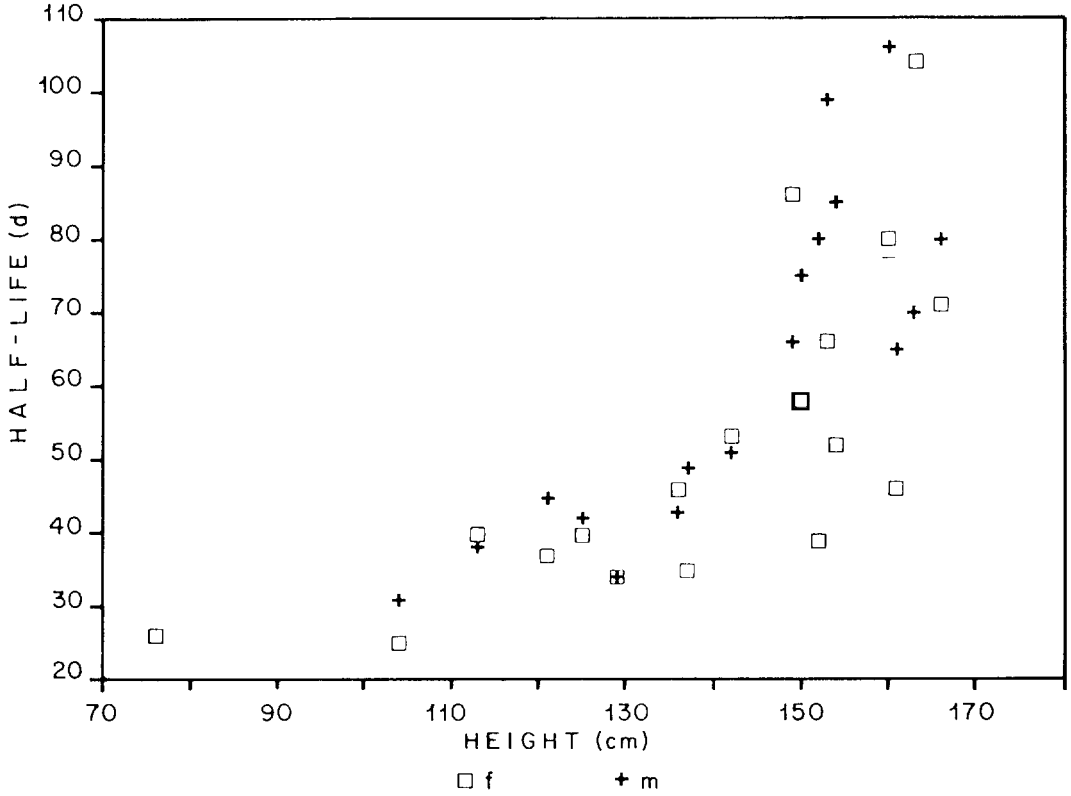

Fig. 2. Height vs. half-life of whole-body retention of ^{137}Cs in subjects contaminated with ^{137}Cs from the Goiânia accident.

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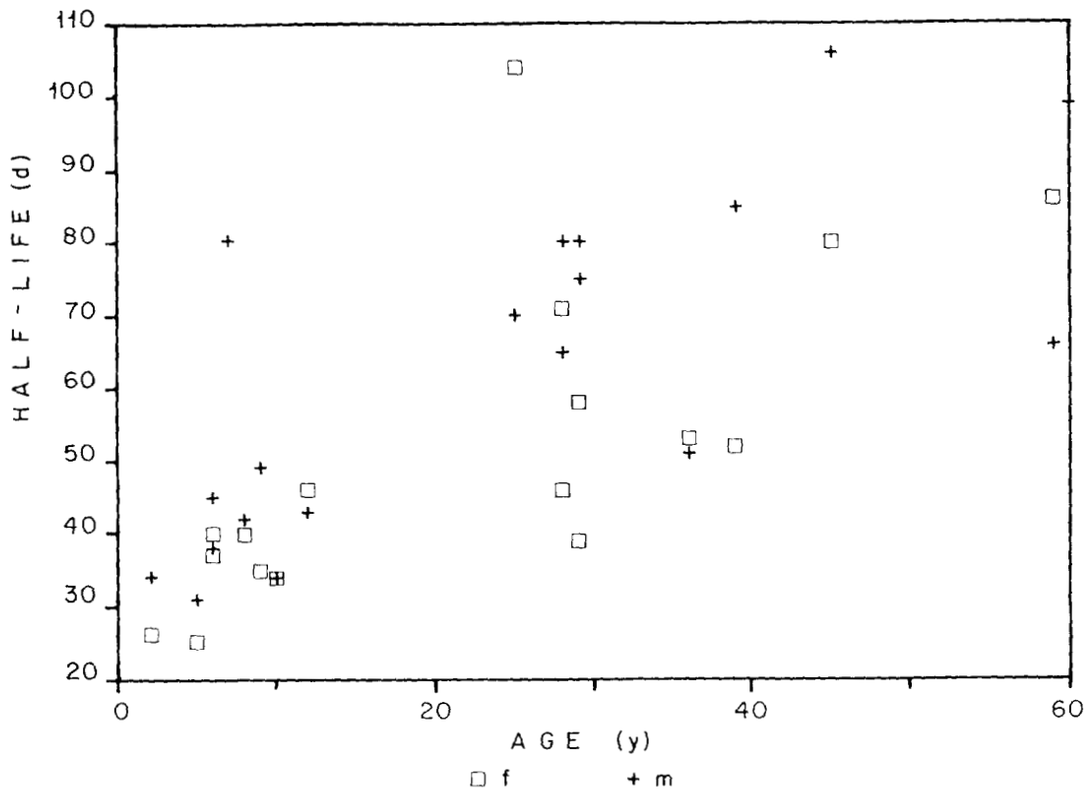

Fig. 3. Age vs. half-life of whole-body retention of ^{137}Cs in subjects contaminated with ^{137}Cs from the Goiânia accident.

low to confirm and help explain the relationship between initial burden and half-life.

Table 3 shows the half-life ratios between Prussian Blue treatment at 3, 6, and 10 g d^{-1} and no treatment at all and the weight of each individual that received the medication. Except for one subject, all males that were given 3 g d^{-1} of Prussian Blue were children weighing less than 30 kg. Those children showed a mean reduction in half-life of 32%. For the entire 3 g d^{-1} treatment group, the average reduction was 28%. For the 6 g d^{-1} treatment group the mean reduction was 31%, while for the 10 g d^{-1} group it was 32%. When comparing these mean reductions in half-lives, it should be noted that different doses of Prussian Blue were given to different age, weight, and body-burden groups. Our results have shown a smaller reduction in biological half-life than the one found in the literature (IAEA 1988).

The male subject weighing more than 30 kg in the 3 g d^{-1} treatment group experienced a less-effective reduction in half-life from medication (12%) than his lighter peers ($\bar{x}$ = 32%) at the same treatment dosage group. The female group had two adults who were given 3 g d^{-1} of Prussian Blue. They have also shown a less-effective reduction in half-lives (12% and 10%) than the 20-kg child

Table 3. Ratio between half-lives obtained under treatment with Prussian Blue and after treatment as a function of weight for males and females exposed to ^{137}Cs in the Goiânia accident.

Weight (kg)	Prussian Blue dosage (g d^{-1})		
	3	6	10
Males			
23.00	0.60		
25.00	0.74		
26.50	0.68		
27.50	0.71		
31.00			0.57
38.00			0.63
55.00			0.65
61.00		0.70	
63.00			0.74
69.50	0.88		
69.50		0.71	
69.50			0.81
73.50		0.78	
80.00		0.58	
Females			
20.00	0.65		
42.00	0.90		
58.00	0.88		
66.00			0.63

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that was given 3 g d^{-1} of the medication (35% reduction in half-life) and the adult who was given 10 g d^{-1} (37% reduction). Although these data are not enough for any valid statistically reliable conclusion, they give us a hint that there might be an optimum dosage of Prussian Blue for certain weight ranges, which would enhance ^{137}Cs elimination from humans at maximum efficiency. Animal experiments should be done to clarify these results.

CONCLUSION

Eliminating ^{137}Cs from humans seems to follow a first-order kinetic pattern, with all exponential regression curves fitting experimental data with correlation coefficients significantly different from zero ($p < 0.01$). This conclusion applies for the individuals under and without Prussian Blue treatment.

Females presented a wider distribution of half-lives than males, as already noted by Leggett et al. (1984). Of all biological parameters analyzed—age, weight, and height—weight had the greatest influence on half-life.

The initial body burden for natural elimination of ^{137}Cs, without the influence of Prussian Blue, showed some significant inverse linear correlation with the nuclide effective half-life. Its influence was not as strong as the weight.

In general, for the male group, the mean reduction in half-lives by the action of Prussian Blue was 32%, but different dosages of the drug were given to different age (weight) groups.

Two adult women and one 15-y-old boy with adult weight and height (69 kg, 174 cm) were treated with 3 g d^{-1} Prussian Blue. They experienced the smallest effect from treatment, 10 to 12% half-life reduction, in comparison to a mean of 32% for children under 30 kg in the same treatment group and all other patients at higher dosages. Although not statistically reliable because of the small number of data, these results suggest an optimum dosage for a certain weight range for maximum results from treatment.

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REFERENCES

International Atomic Energy Agency. Medical handling of accidentally exposed individuals. Vienna: IAEA; Safety Series 88; 1988.

International Commission on Radiological Protection. Limits for intakes of radionuclides by workers. Oxford: Pergamon Press; ICRP Publication 30, Part 1; Ann. ICRP 2(3/4):1–116; 1979.

Leggett, R. W. Predicting the retention of Cs in individuals. Health Phys. 50:747–759; 1986.

Leggett, R. W.; Eckerman, K. F.; Dunning, D. E.; Cristy, M.; Crawford-Brown, D. J.; Williams, L. R. On estimating dose rates to organs as a function of age following internal exposure to radionuclides. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-8265; 1984.

Oliveira, C. A. N.; Lourenço, M. C.; Dantas, B. M.; Lucena, E. A. Design and operation of a whole-body monitoring system for the Goiânia radiation accident. Health Phys. 60:51–55; 1991.

SAS Institute Inc. SAS/STAT guide for personal computer. Version 6 edition. Cary, NC: SAS Institute Inc.; 1985.

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