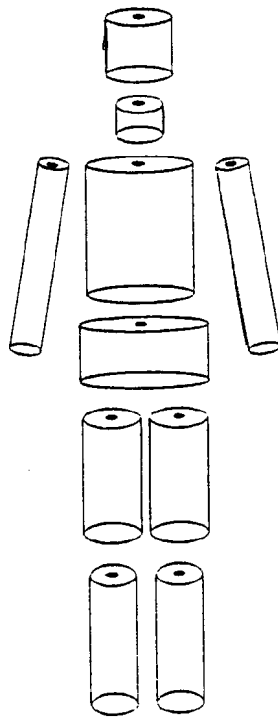




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PHANTOMS



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INTRODUCTION

This document describes the criteria used in designing the phantoms used for calibrating a whole body counter for high energy photon emitters (>200 keV). The document also describes the procedures, material sources, Quality Control (QC) checks, and the equipment required to verify the elliptical phantoms (also known as Bottle Mannequin Absorber phantoms: BOMAB) used in the whole body intercomparison/calibration program of the Human Monitoring Laboratory (HML) at the Bureau of Radiation and Medical Devices.

It is intended that this document provide sufficient information to ensure that future extensions in design are consistent with the BRMD BOMAB Phantom Family. It is further intended that this document be used as the core for training personnel to perform these measurements for phantom design, verification and usage.

The purpose of the phantoms is for calibration and intercomparison of Canadian In-Vivo Facilities: the necessary requirement is to create a series of well defined phantoms of differing sizes that closely approximate the ICRP reference values.

In this document the various BOMAB phantoms are identified by acronyms. These are defined below:

- o PMx Phantom Reference Male
- o PFx Phantom Reference Female
- o PIOx Phantom Reference 10 year old
- o P4x Phantom Reference 4 year old
- o PMSx Phantom Male Fifth Percentile
- o PM95x Phantom Male Ninety Fifth Percentile

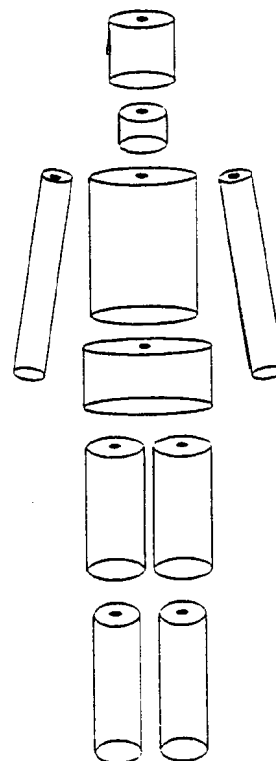
The "x" in the acronym is replaced by A-Z for each member of the phantom series i.e. PMA, PMB,

The P4 series has been modified so that the shortcomings of P4A and P4B, which are the early members of the series, have been removed. P4C and subsequent phantoms in the P4 series are more representative of a 4 year old.

Figure 1: BOMAB Phantom**DESCRIPTION OF THE PHANTOMS**

The BOMAB phantom is comprised of ten elliptical containers (bottles) as shown in figure 1. The PM95 phantom is, of course, an exception: it is comprised of eleven elliptical containers. Each section of the phantom has a recessed filling cap located in the end-face (the ellipse end: see figure 1). When assembled together they will approximate the physical shape of a human but the phantom does not attempt to simulate complete anthropomorpicity This apparent failing in the design is not considered to be important for the following reasons:

- o The bulk of the human body consists of water which is the material used to fill the bottles.
- o The attenuation of the photons by higher density materials becomes less important as the energy of the photon rises. These phantoms are designed to be used with high energy emitters (>200 keV); calibrations for low energy photons are described elsewhere (1,2)
- o The modeling of the human shape and location of the activity can be adequately performed with the BOMAB phantoms

**DESIGN OF THE REFERENCE PHANTOMS**

The International Commission on Radiological Protection (ICRP). published the findings of the Task Group on Reference Man (3) This report assigns values for most anatomical and physiological values to Reference Man and Reference Woman. The report also assigns some values to Reference Child (10 yr old) and Reference Infant (1 yr old), in addition to listing some anatomical values for other age ranges. The Reference Infant was deemed to be too small for a BOMAB phantom; however, it was recognized that a small phantom a necessary to investigate & response of a whole body counters at this extreme. The compromise age was chosen to be 4 years old.

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Table I: Reference Values

	Male	Female	10 yr	4 yr
Weight (kg)	70	58	34	18
Height (cm)	170	160	140	105

The values for weight, height (body length) and SA (surface area) that were extracted from ICRP 23 (3) are shown in Table I. These values and those of the following tables were used to formulate the dimensions of the ellipsoidal cylinders that comprise the phantom; therefore, the parameters of interest for each section are the cylinder height Q, the ellipse semi-major axis (2a) and the ellipse semi-minor axis (2b). The theoretical values that correspond to the appropriate reference phantom are shown in Appendix 2.

Using these values one can calculate what the characteristics of the phantoms should be after construction. ICRP 23 provides other Surface Area information (see Table II) that were useful in refining the dimensions and volumes of the various phantom sections. JCRP 23 also gives guidelines about the volume of selected sections of the body. The relevant data is shown in table III. The Trunk section includes the neck, chest and gut; the calves include the feet; and the arms include the forearms, hands and upper arms.

Table II Other Surface Area Data from ICRP23

	Surface Area		
(%)			
Section	Adult	10 yr	4 yr
Head	-	10	14
Head & Neck	9	-	-
Torso & Neck	-	33	33
Torso	36	-	-
Upper Limbs	18	20	19
Lower Limbs	36	37	34

Table III: Relative Volume of Body Sections

	Adult	10 yr	4 yr
Head	6	12	18
Trunk	51	51	53
Thighs	18	16	10
Calves	13	12	10
Arms	12	9	9

The original dimensions for P10 and P4 were obtained simply by scaling down reference man. The original values for the head are shown in parentheses for comparison (Appendix 2). Further refinements for the body sections for all phantoms was performed used the data shown below.

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These calculated Values are shown in table IV and it can be seen that the ICRP values above are quite closely reproduced except for the surface area of the 10 year old phantom; however, this is not deemed to be a critical requirement at this time.

Table IV Derived Phantom Characteristics

	Man	Woman	10 yr	4 yr
Wt (kg)	70.10	56.07	35.87	18.99
HT (cm)	169.5	160.2	140.0	105.3
Sa (cm ²)	18642	16145	12166	7773

DESIGN OF THE PERCENTILE PHANTOMS

To fully test the "calibration surface" of a whole body counter for different physical types it was decided to extend the phantom family to include some extremes of physique in the population. For the first design a male phantom was chosen. ICRP has no data for this member of the population so other sources were examined (5, 6, 7). It was decided to use Canadian data (5, 6) which was more current than the corresponding United States data (7).

The first design criteria was set at 95 and 5 percentile for height and weight. Examination of the data (5, 6) showed that within each set (weight or height) there were percentile ranges. In other words, a physique corresponding to 95 percentile height had a sub-set of weight percentiles.

Table V: Heights (cm) for the 95 and 5 Percentile Canadian Male

Percentile					
Age	5	25	50	75	95
30-39	161.8	168.0	172.9	178.1	184.6
40-49	160.2	167.6	171.9	176.4	184.5
Target	161				184

The first design was, therefore, set to be the 95 and 5 percentile weights of the 95 and 5 percentile heights for a Canadian male. This first design could, therefore, be thought of as a percentile-percentile phantom.

The heights for the percentile phantoms were selected from the Canadian Adult male population (5) in the age group 30-49 years. This sub-set was composed of approximately 2,500,000 individuals and the resulting target heights are shown in table V. The target weights were then selected for these heights and an example of the data (6) is shown in table VI. The target weights are shown in **bold** type.

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Additional anthropomorphic data that were used in refining the dimensions of the percentile phantoms

are:

- o Sitting height (the height of the trunk, neck and head)

- o Relative Sitting Height (the sitting height divided by total height)

The actual dimensions of the percentile phantoms were initially derived from the reference man

phantom by simply multiplying each dimension by a factor derived from the total height and weight ratios of reference man to the target values

described above. The derived dimensions

were then fine tuned to attempt to get closer to the values shown in tables VI and VII. The final values showed that the PM95 phantom would have a large heavy torso.

Table VI: Percentiles for Weight (kg) for a Given Height (cm) of Adult Canadian Males

Percentiles Height (cm)	5	25	50	75	95
158-162	51	60	65	72	81
163-167	50	60	67	74	87
168-172	55	64	72	81	91
173-178	60	67	76	82	93
179-182	61	72	79	84	93
183-187	68	79	88	94	105
188 +	73	79	89	104	104

To reduce the weight and improve the handling characteristics of this section it was decided to create the PM95 phantom from 11 sections by dividing the chest section into an upper and lower section. The height of the two sections was not set equal. The height of the upper chest section includes the lungs and the height of the lower section corresponds to the lower organs of the chest.

The manufacturing process has complied with the original values (appendix 2) quite closely; however, some sections have been made more circular - arms, thighs, neck and calves. The best comparison is obtained by comparing each section of the phantom as a percentage of the whole

phantom. The comparison of the percentage of each section as a function of the whole body shows reasonable agreement between the derived values Heights (appendix 2), the measured values Sitting (appendix 3) and the reference values extracted from ICRP.

Table VII Comparison of other Anthropomorphic Data

(percentile)	Reference Values			
Heights	PM95	PM5	95	5
Sitting (cm)	97.2	84.9	97.4	86.1
Relative Sitting	0.523	0.528	0.555	0.510

The percentile phantoms cannot be compared to "reference" values. In this case the comparison of the measured values

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is made with the derived (anthropomorphic data) values and the values

The comparison is shown in table VIII. It is clear, however, that the phantoms have slightly larger calves, arms and thighs compared to the ICRP reference values and slightly smaller trunks and heads. The poorest agreement is with the 4 yr old. However, this phantom is designed to test an extremity of calibration instead of faithfully mimicking an employee; therefore, this discrepancy is not considered important. The latest addition

to the P4 series has been modified to remove these shortcomings. The data for this phantom are shown above both in parentheses in the above table and in the appendicies.

Comparison of the gross volumes of the calculated and measured values also show that there is a reasonable consistency between the phantoms and that they do indeed approximate the desired reference sizes that were discussed above. Similarly, the height values compare well with the derived data given in Table 1.

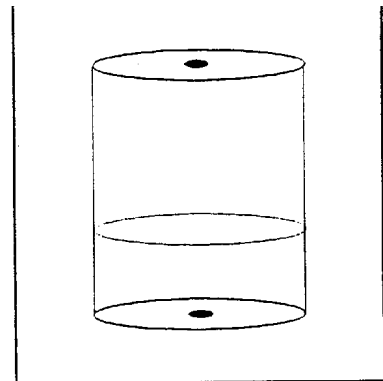
2 Modified Chest Section for PM series

ACCESSORY CHEST FOR PM SERIES

The re-design of the PM95 phantom to include an upper chest (containing the lungs) and a lower chest (containing the ower organs) prompted the design of an accessory section for the reference man phantom. A single chest section was designed with a wall to separate the upper and lower sections see figure 2. This accessory will allow the reference man phantom to better simulate a lung deposition. The characteristics of the accessory section are shown in appendix 3.

of Body Sections (%)		Table VIII Comparison			
Head	6	12	18	ICRP	
	6	9	13(17)	Derived	
	6	8	14(17)	Measured	
Trunk	51	51	53	ICRP	
	46	45	44(53)	Derived	
	48	48	44(53)	Measured	
Thighs	18	16	10	ICRP	
	21	21	20(10)	Derived	
	21	22	19(10)	Measured	
Calves	13	12	10	ICRP	
	14	13	13(10)	Derived	
	13	11	13(10)	Measured	
Arms	12	9	9	ICRP	
	12	11	11(10)	Derived	
	12	10	10(10)	Measured	

Figure



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ACCESSORY OVERLAY PLATES FOR PM SERIES

A series of overlay plates, constructed from high density polyethylene, has been manufactured for the PM series. There is a plate for each of:

- Chest section
- Gut Section
- Each thigh section

Each plate is approximately 1.25 cm thick. The curvature of each plate is such that the plates can be stacked upon each other to give a total overlay thickness of 5 cm. The overlay plates are designed to be used to simulate individuals that have a thicker adipose tissue layer than Reference Man. The use of the overlay plate series makes the assumption that any internally deposited activity does not reside in this tissue layer.

THE ANSI PHANTOM

The US has decided to use a Reference five-year old for its smallest size. This laboratory supplied the design criteria for that phantom. The data may be found elsewhere (8).

CONSTRUCTION OF THE PHANTOMS

The phantoms were constructed by Canus Plastics¹ using the dimensions shown in appendix 2 as a starting point. The material of choice was high-density polyethylene and its characteristics are summarised in appendix 1. The attenuation coefficients, which are summarised in appendix 5, were measured in the Human Monitoring Laboratory using a sample block supplied by Canus Plastics.

Canus Plastics have created a set of molds made out of wood covered with metal (aluminium or galvanised iron) that approximated the dimensions shown in appendix 2. To simplify the construction on the phantom parts the neck, arms, calves and thighs were made into cylinders (i.e. the semi major axis and semi minor axis were set equal). The molds are covered sheets of polyethylene, placed in an oven and removed when the polyethylene is pliable. The phantom parts are quickly processed to wrap the polyethylene around the mold and the seams are joined using a polyethylene welding gun. The molds are currently stored at Canus Plastics.

The company does not have an in-house QA program so that each phantom must be verified after construction by the HML. This is performed by measuring the outer dimensions of each section, weighing the phantom empty, and filled with water. Initial measurements on the phantom included both volume and weight measurements. The complete set of dimension (2a, 2b, and h) and weight measurements are shown in appendix 3.

The volume/weight data shown in appendix 3 shows that there was essentially no difference between the MO techniques of characterising the sizes of the phantoms. A comparison of the volume with full weight adjusted by empty weight gives results that agree to within 0.6%, except for P4A. The discrepancy of 7% is attributed to measurement error. Based on these results it was decided that all subsequent measurements be performed using the weighing technique.

It was also recognised that the elliptical cylinders are not geometrically perfect .

Filling the phantoms sections with water also performs the important and necessary leak testing. Canus Plastics pressurises the phantom sections to 5 psi but experience shows the plastic welds are not stable with time immediately following construction. Leaks may appear up to one month after construction.

Quantify this was made by performing replicate measurements on a randomly selected phantom, PFB, to ascertain the variability in the parameters 2a, 2b and h. The results are shown in appendix 3.

It was also necessary to verify the accuracy of the scale prior to performing these measurements. This was performed by filling six containers with water and weighing each container on a top loading balance that is accurate to = 0.1 g. These containers were then used as "standard" weights to check the accuracy of the scales. The data, presented in appendix 4, show the accuracy of the scales to be approximately 1% and linear over the weight range of interest.

The accuracy of measurements was also tested by re-weighing some selected (sections that weighed less than 4 kg) sections of PMS and PM95. This data is also presented in appendix 4. The observed bias is almost certainly due to differences in the amount of water that was actually placed in the phantom sections. It was also found to be quite difficult to remove all air bubbles once the liquid reached the GUing hole. Assuming these measurements define the accuracy of the phantoms sections it appears that there may have been a positive bias of 0.035 kg per section measurement. If this is true then the total overestimate could be 0.35 kg which is equivalent to an overestimate of 0.5%; therefore, one concludes that the phantoms characteristics have been estimated to within 1%.

With one exception, all phantoms were characterized in the HML as described above. The P4C phantom was also characterised at Pacific Northwest Laboratories and that data is presented in this document.

CONCLUSION

The phantoms described in this document have been constructed and are currently used in the Human Monitoring Laboratory's Imercalibration program in Canada. All future phantoms will be constructed according to the guidelines and specifications set out within this document. This will ensure that consistency and a close parallel to ICRP recommendations, where appropriate, are maintained.

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APPENDIX 1. Properties* of High-Density Polyethylene

<u>Property</u>	<u>Value</u>	<u>Units</u>
Specific Gravity	0.941-0.965	
Specific Volume	29.4-28.7	(in ³ .lb ⁻¹)
Refractive Index	1.54	nD
Tensile Strength	3100-5500	psi
Elongation 15-100	%	
Modules of Elasticity in tension	0.8-1.5	10 ³ .psi
Compressive Strength	2400	psi
Flexural strength	1000	psi
Impact Strength	1.5-12	ft-lb per in of notch
Hardness, Rockwell	D60-D70	
Thermal Conductivity	11-12.4	10 ⁴ cal sec ⁻¹ cm ⁻² , per deg C cm ⁻¹
Specific Heat	0.55	cal °C ⁻¹ g ⁻¹
Thermal Expansion	11-13	10 ⁻³ °C ⁻¹
Resistance to Heat	250	°F (continuous)
Heat Distortion Temp	140-180	°F (at 66 psi)
Volume Resistivity	10 ¹³ -10 ¹⁶	ohm-cm (50% rel Humidity at 23 °C)
Dielectric Strength	450-500	short time, 0.125" thick. V mil ⁻¹
Dielectric Strength	440-600	stepwise, 0.125" thick Vmil ⁻¹
Dielectric Constant	2.25-2.35	60 cycles
Dielectric Constant	2.25-2.35	10 ³ cycles
Dielectric Constant	2.25-2.35	10 ⁶ cycles
Dissipation (power) factor	<0.0005	60 cycles
Dissipation (power) factor	<0.00021	10 ³ cycles
Dissipation (power) factor	<0.0003	10 ⁶ cycles
Are Resistance	-	sec
Water Absorption	<0.01	24 hr, 0.125" thick, %
Burning Rate	Very Slow	
Effect of Sunlight	Requires Black	
Effect of Weak Acid	Very Resistant	
Effect of Strong Acid	Attacked slowly by oxidising acids	
Effect of Weak Alkalies	Very Resistant	
Effect of Strong Alkalies	Very Resistant	
Effect of Organic Solvents	Resistant below 80°C .	
Clarity Translucent to opaque		

* Information from Cadillac Plastic (Canada) Ltd.

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APPENDIX 2: Reference Phantom Theoretical Dimensions.

Section	2a cm	2b cm	h cm	vol L	% vol	Phantom
Head	19.05	14.61	19.68	4.301	6.1	Man
	17.50	13.00	18.00	3.216	6.5	Man (5%)
	20.50	15.50	21.50	5.365	5.1	Man(95%)
	17.53	13.46	18.49	3.426	6.1	Woman
	18.67	14.22	16.26	3.390	9.4	10 yr
	18.03	13.89	12.19	2.398	12.6	4 yr
	21.00	15.00	12.50	3.093	17.2	4 yr modified
	(14.83	11.38	16.26	2.155	6.2	10 yr)
	(12.19	9.40	12.19	1.097	6.2	4 yr)
	Neck	14.76	13.69	9.52	1.511	1.6
12.00		12.00	9.00	1.018	2.0	Man(S%)
15.00		15.00	10.40	1.838	1.7	Man(95%)
13.46		12.7	8.94	1.200	2.1	Woman
11.48		10.67	7.87	0.757	2.1	10 yr
9.40		8.64	5.84	0.373	2.0	4 yr
9.40		8.64	5.30	0.338	1.9	4 yr modified
Chest		29.84	20.65	41.60	20.133	28.7
	28.00	18.00	39.20	15.517	31.2	Man(5%)
	36.00	27.50	28.00	21.771	20.6	Man(95%) ¹
	36.00	27.50	17.00	13.218	12.5	Man(95%)
	27.43	19.05	39.09	16.042	28.6	Woman
	23.27	16.00	34.04	9.954	27.6	10 yr
	19.05	13.21	25.65	5.070	26.7	4 yr
	19.50	15.50	25.70	6.101	33.8	4 yr modified

1. Due to the projected size and weight of a single chest section it was decided to split this section and design two chest parts.

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Section	2a cm	2b cm	h cm	vol L	% vol	Phantom
Gut	36.19	19.68	20.17	11.282	16.1	Man
	30.00	16.00	19.10	7.200	14.5	Man(5%)
	40.00	30.00	22.00	20.734	19.7	Man(95%)
	33.40	18.14	18.95	9.017	16.1	Woman
	28.19	15.24	16.51	5.571	15.5	10 yr
	23.11	12.45	12.45	2.813	14.8	4 yr
	23.50	13.50	12.50	3.115	17.3	4 yr modified
Arm	9.52	9.52	58.11	4.136	11.8	Man
	8.50	8.50	52.00	2.951	5.9	Man(5%)
	10.50	10.50	72.00	6.234	5.9	Man(95%)
	8.79	8.79	54.61	3.313	11.8	Woman
	7.37	7.37	47.75	2.037	11.4	10 yr
	6.10	6.10	35.81	1.046	11.0	4 yr
	5.70	5.70	35.81	0.914	11.1	4 yr modified
Thigh	16.18	14.94	39.70	7.537	21.5	Man
	13.50	13.50	37.90	5.425	10.9	Man(5%)
	16.00	16.00	43.50	8.746	8.3	Man(95%)
	14.97	13.77	37.31	6.040	21.5	Woman
	12.70	11.68	32.51	3.788	21.1	10 yr
	10.41	9.40	24.51	1.884	19.8	4 yr
	6.80	6.80	24.50	0.890	9.9	4 yr modified
Calf	12.55	12.13	39.83	4.762	13.6	Man
	10.00	10.00	38.00	2.985	6.0	Man(5%)
	13.50	13.50	44.00	6.298	6.0	Man(95%)
	11.68	11.18	37.44	3.840	13.7	Woman
	9.40	9.40	32.77	2.274	12.7	10 yr
	8.00	8.00	24.64	1.238	13.0	4 yr
	6.80	6.80	24.50	0.890	9.9	4 yr modified

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Outer dimensions of the phantoms PM95 series

Section	2a (cm)	
	PM95A	PM95B
Head	20.50	20.40
Neck	15.70	14.70
Chest (upper)	35.60	36.05
Chest (lower)	36.20	35.95
Gut	40.00	42.50
Right Ann	11.20	10.15
Left Arm	10.60	10.70
Right Thigh	17.00	16.55
Left Thigh	17.10	16.10
Right Calf	13.90	13.80
Left Calf	13.40	13.80

Section	2b (cm)	
	PM95A	PM95B
Head	16.10	15.50
Neck	14.80	14.95
Chest (upper)	27.90	27.70
Chest(lower)	28.00	27.70
Gut	29.80	30.00
Right Arm	10.20	10.65
Left Arm	10.60	10.40
Right Thigh	16.20	16.45
Left Thigh	16.30	16.10
Right Calf	13.40	13.20
Left Calf	13.20	13.30

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APPENDIX 3. ELLIPTICAL PHANTOM MEASUREMENTS

Volume Measurements (L)

Section	P4A	P4B	PMA	PMB
Head	1.70	1.73	3.59	3.47
Neck	0.18	0.19	0.83	0.83
Left Arm	0.62	0.62	3.76	3.86
Right Arm	0.62	0.63	3.81	3.63
Chest	3.63	3.62	16.70	16.35
Gut	1.95	1.89	10.86	10.90
Left Thigh	1.26	1.27	6.46	6.46
Right Thigh	1.24	1.27	6.35	6.43
Left Calf	0.85	0.83	3.85	4.09
Right Calf	0.84	0.80	4.07	4.06
Total	12.88	12.84	60.27	60.07

% by volume

Section	P4A	P4B	PMA	PMB
Head	13.17	13.45	5.96	5.77
Neck	1.37	1.45	1.37	1.38
Left Arm	4.84	4.81	6.23	6.42
Right Arm	4.81	4.91	6.32	6.04
Chest	28.18	28.17	27.71	27.22
Gut	15.10	14.72	18.01	18.15
Left Thigh	9.80	9.89	10.72	10.75
Right Thigh	9.66	9.89	10.54	10.70
Left Calf	6.60	6.46	6.39	6.81
Right Calf	6.48	6.25	6.75	6.76

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Outer dimensions of the phantoms PM series

Section	2a (cm)							
	PMA	PMB	PMC	PMD	PME	PMF	PMG	PM5
Head	18.60	18.00	19.10	19.00	19.10	18.80	19.00	17.90
Neck	12.70	12.50	14.80	12.70	15.00	13.00	12.60	11.60
Chest	29.00	28.40	29.60	29.70	29.20	29.90	29.30	28.20
Gut	35.70	35.85	36.20	36.10	33.90	35.90	36.40	29.50
Right Ann	10.35	9.80	9.50	10.00	10.00	10.00	10.10	8.90
Left Arm	10.00	10.30	10.10	10.00	10.40	10.20	10.15	9.30
Thigh	15.60	15.60	15.90	14.70	15.80	14.90	15.20	13.10
Left Thigh	15.85	15.70	15.60	14.60	15.90	15.00	15.30	13.00
Right Calf	12.80	12.60	12.40	11.80	12.20	12.00	12.70	10.10
Left Calf	12.40	12.50	12.50	11.80	12.30	11.80	12.70	9.70

Section	2b (cm)							
	PMA	PMB	PMC	PMD	PME	PMF	PMG	PM5
Head	13.90	13.70	14.20	14.20	14.70	14.00	14.40	13.30
Neck	12.70	12.40	14.70	12.60	14.90	12.90	12.50	11.30
Chest	19.20	18.80	20.80	20.20	19.50	19.90	20.90	18.30
Gut	20.00	19.90	19.80	20.80	18.80	20.20	19.80	16.40
Right Arm	9.90	9.50	9.10	10.00	9.50	10.00	9.90	8.60
Left Arm	9.60	9.95	9.90	10.00	9.70	10.00	9.90	8.90
Right Thigh	15.70	15.50	14.80	14.70	14.80	14.80	15.10	13.00
Left Thigh	15.50	15.40	15.30	14.60	14.90	14.80	15.10	12.80
Right Calf	12.50	12.50	11.80	11.70	11.60	11.90	12.50	9.90
Left Calf	12.40	12.40	11.50	11.80	11.80	11.80	12.40	9.60

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h (cm)

Section	PMA	PMB	PMC	PMD	PME	PMF	PMG	PM5
Head	22.40	22.50	19.70	19.80	19.70	19.90	19.70	17.60
Neck	10.10	10.10	9.45	9.40	9.50	9.90	9.90	9.10
Chest	43.10	43.10	41.60	41.90	41.70	39.90	41.65	38.90

Gut	22.70	22.80	20.20	20.10	20.10	20.10	20.00	19.30
Right Arm	60.95	61.00	58.30	59.40	58.10	59.90	60.80	51.50
Left Arm	61.10	61.00	58.25	59.45	58.30	60.10	60.85	51.10
Right Thigh	40.60	40.50	39.90	40.40	39.90	39.90	40.40	37.50
Left Thigh	40.40	40.45	40.00	40.30	39.90	39.90	40.50	37.70
Right Calf	40.60	40.60	39.80	40.00	40.00	40.10	40.60	37.90
Left Calf	40.50	40.60	39.80	40.00	40.00	40.10	40.60	38.20

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h (cm)

Section	PM95A	PM95B
Head	21.10	21.30
Neck	10.40	10.55
Chest (upper)	27.20	28.20
Chest (lower)	16.90	17.00
Gut	21.60	22.05
Right Arm	71.90	71.80
Left Arm	72.40	71.30
Right Thigh	44.20	43.00
Left Thigh	44.00	43.00
Right Calf	44.40	44.20
Left Calf.	43.90	43.90

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Outer dimensions of the phantoms PF series

2a (cm)

Section	-PFB replicate measurements-					Mean		PFA
Head	17.60	17.60	17.60	17.60	17.60	17.60	0.00	17.30
Neck	12.90	13.05	13.05	13.00	13.10	13.02	0.58	12.90
Chest	26.95	26.90	26.90	26.90	26.90	26.91	0.08	26.80
Gut	33.30	33.20	33.30	33.25	33.30	33.27	0.13	32.90
Right Ann	8.60	8.60	8.75	8.60	8.65	8.64	0.75	8.35
Left Arm	8.80	9.25	9.15	9.20	9.30	9.14	2.17	8.30
Right Thigh	14.30	14.40	14.50	14.40	14.40	14.40	0.49	14.20
Left Thigh	14.20	14.30	14.50	14.40	14.50	14.38	0.91	14.40
Right Calf	11.20	11.30	11.35	11.40	11.35	11.32	0.67	11.20
Left Calf	11.20	11.35	11.30	11.30	11.40	11.31	0.66	11.10

2b (cm)

Section	--PFB replicate measurements-					Mean		PFA
Head	13.20	13.70	13.70	13.70	13.70	13.60	1.64	13.70
Neck	12.80	12.90	12.90	12.90	12.90	12.88	0.35	12.70
Chest	18.80	18.80	18.85	18.80	18.90	18.83	0.24	19.00

Gut	18.25	18.20	18.30	18.20	18.20	18.23	0.25	18.90
Right Arm	8.50	8.50	8.60	8.60	8.65	8.57	0.78	8.15
Left Arm	8.60	9.00	9.00	9.10	9.10	8.96	2.31	8.20
Right Thigh	14.10	14.20	14.40	14.25	14.40	14.27	0.91	13.90
Left Thigh	14.10	14.30	14.50	14.40	14.45	14.35	1.10	13.70
Right Calf	10.90	11.20	11.20	11.20	11.30	11.16	1.36	10.90
Left Calf	11.10	11.05	11.20	11.05	11.10	11.10	0.55	10.80

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Section	h (cm)					Mean	o	PFA
	-PFB replicate measurements-							
Head	18.40	18.30	18.40	18.40	18.40	18.38	0.24	18.40
Neck	11.00	11.20	11.30	11.15	11.15	11.16	0.97	11.20
Chest	39.00	38.90	39.00	39.00	38.90	38.96	0.14	38.90
Gut	18.80	18.80	18.80	18.70	18.80	18.78	0.24	18.80
Right Arm	54.20	54.20	54.30	54.20	54.30	54.24	0.10	54.20
Left Arm	54.30	54.20	54.30	54.30	54.25	54.27	0.07	34.15
Right Thigh	37.00	36.90	36.95	36.90	37.00	36.95	0.14	37.10
Left Thigh	36.85	36.80	36.85	36.80	36.90	36.84	0.11	37.10
Right Calf	37.20	37.15	37.20	37.20	37.25	37.20	0.10	37.30
Left Calf	37.25	37.30	37.30	37.25	37.30	37.28	0.07	37.00

Theoretical volumes for PM series (ml)

Section	PMA	PMB	PMC	PMD	PME	PMF	PMG	PMS
Head	4548	4358	4196	4196	4344	4114	4233	3291
Neck	1279	1230	1615	1181	1668	1304	1225	937
Chest	18848	18074	20116	19743	18648	18646	20032	15767
Chest								
Gut	12730	12775	11371	11854	10061	11448	11321	7334
Right Arm	4905	4460	3958	4665	4335	4705	4775	3096
Left Arm	4607	4910	4574	4669	4619	4815	4802	3322
Right Thigh	7810	7691	7374	6857	7328	6911	7283	5016
Left Thigh	7795	7681	7498	6747	7424	6957	7349	4927
Right Calf	5102	5022	4574	4337	4446	4497	5062	2976
Left Calf	4891	4943	4493	4374	4360	4385	5022	2794
Total	67967	66786	65575	64428	63089	63667	66870	49459

(Theoretical volumes for PF and PM95 series (ml)

Section	PFB	PFA	PM95A	PM95B
Head	3455	3425	5470	5290
Neck	1470	1441	1898	1821
Chest	35505	15557	21218	22117
Chest (lower)			13454	13296
Gut	8946	9181	20222	22080

Right Arm	3154	2897	6451	6096
Left Arm	3491	2895	6389	6232
Right Thigh	5963	5751	9560	9194
Left Thigh	5971	5748	9632	8754
Right Calf	3691	3576	6495	6324
Left Calf	3676	3484	6099	6328

Total	55322	53956	106888	107532
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Outer dimensions of the phantoms P10 series (cm)

Section	PIOA	PIOB	PIOA	PIOB	PIOA	PIOB
	2a	2a	2b	2b	h	h
Head	18.10	17.90	13.90	14.00	16.30	16.20
Neck	10.80	10.80	10.30	10.40	7.80	7.80
Chest	23.40	23.30	16.40	16.10	34.00	34.00
Gut	27.50	27.80	15.60	16.10	16.50	16.60
Right Arm	7.00	7.20	6.80	7.00	47.70	47.70
Left Arm	6.90	7.30	6.90	6.80	47.80	47.65
Right Thigh	12.60	11.80	12.50	11.80	32.80	32.50
Left Thigh	12.20	12.60	12.20	12.40	32.50	32.55
Right Calf	9.10	9.15	8.90	8.40	32.50	32.50
Left Calf	9.20	9.10	8.80	8.90	32.70	32.60

Theoretical Volumes for the P10 series (ml)

Section	PIOA	P10B
Head	3221	3188
Neck	681	688
Chest	10248	10017
Gut	5559	5835
Right Arm	1783	1888
Left Ann	1787	1858
Right Thigh	4057	3554
Left Thigh	3799	3994
Right Calf	2067	1962
Left Calf	2079	2074
Total	35283	35059

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Outer dimensions of the phantoms P4 series (cm)

Section	P4A 2a	P4B 2a	P4C 2a	P4A 2b	P4B 2b	P4C 2b	P4A h	P4B h	P4C h
Head	18.10	18.10	20.80	13.80	13.85	15.40	11.90	12.30	12.40
Neck	8.70	8.80	9.40	8.70	8.80	8.80	5.60	5.55	5.40
Chest	18.20	18.35	19.50	12.10	12.60	15.20	25.60	25.50	25.60
Gut	22.90	23.10	23.60	11.80	11.50	13.70	12.10	12.20	13.00
Right Arm	5.60	5.70	6.10	5.60	5.70	5.60	35.90	35.90	36.30
Left Arm	5.70	5.70	5.50	5.70	5.50	5.70	35.80	35.85	36.20
Right Thigh	9.20	9.40	6.70	9.20	9.20	6.30	24.40	24.35	24.60
Left Thigh	9.40	9.40	6.80	9.30	9.30	6.20	24.30	24.40	24.70
Right Calf	7.80	7.60	7.00	7.70	7.50	6.30	24.50	24.40	24.40
Left Calf	7.70	7.50	6.70	7.70	7.60	6.10	24.40	24.50	24.60

Section	P4D 2a	P4D 2b	P4D h
Head	20.55	15.5	12.48
Neck	8.84	8.34	5.32
Chest	19.22	15.25	25.60
Gut	23.28	13.70	12.72
Right Arm	5.82	5.81	35.75
Left Arm`	5.95	5.79	35.62
Right Thigh	6.62	6.53	24.50
Left Thigh	6.61	6.62	24.72
Right Calf	6.62	6.60	24.50
Left Calf	6.54	6.56	24.45

Theoretical Volumes for the P4 series (ml)

Section	P4A	P4B	P4C	P4D
Head	2335	2382	3120	3122

Neck	333	338	351	308
Chest	4428	4631	5959	5893
Gut	2568	2545	3301	3186
Right Arm	884	916	969	949
Left Arm	914	883	844	964
Right Thigh	1622	1654	816	832
Left Thigh	1668	1675	818	850
Right Calf	1156	1092	845	841
Left Calf	1136	1097	790	824
Total	17043	17213	17812	17769

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Theoretical Volume/Measured Height Summary

Phantom	Volume (ml)	Height (cm)
PMA	67967	179.50
PMB	66786	179.60
PMC	65575	170.65
PMD	64428	171.60
PME	63089	170.90
PMF	63667	169.80
PMG	66870	172.25
PFA	53956	161.70
PFB	53522	161.51
P1OA	35283	140.10
P1OB	35059	139.70
P4A	17043	104.10
P4B	17213	104.25
P4C	17812	105.70
P4D	17769	105.34
PM5	49459	160.80
PM95A	106888	185.80
PM95B	107532	186.30

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Empty Weight Measurements (kg)

Section	PMA	PMB	PMF	PMC	PMD	PMG	PFA	PFB	PME
Head	0.93	0.90	0.73	0.93	1.07	0.90	0.81	0.75	0.93
Neck	0.45	0.45	0.35	0.51	0.48	0.44	0.47	0.45	0.51
Left Arm	1.00	1.00	1.00	0.90	1.03	1.06	0.58	0.80	0.90
Right Arm	0.98	0.98	1.00	0.95	1.05	1.00	0.58	0.75	0.95
Chest	2.45	2.40	1.95	2.53	2.83	2.50	2.07	2.00	2.53
Gut	2.15	2.15	1.73	2.05	2.03	2.00	1.74	1.70	2.05
Left Thigh	1.28	1.30	1.00	1.23	1.36	1.22	1.06	1.10	1.23
Right Thigh	1.30	1.28	1.00	1.25	1.34	1.19	1.05	1.00	1.25
Left Calf	0.93	1.00	0.93	0.90	0.95	0.98	0.76	0.80	0.90
Right Calf	0.95	0.95	0.93	0.90	0.97	1.02	0.78	0.75	0.90
Total	12.40	12.40	10.60	12.13	13.11	12.31	9.88	10.10	12.13

Section	P4A	P4B	P4C	P4D	P1OA	P1OB	PMS	PM95A	PM95B
Head	0.40	0.68	0.84	0.98	0.83	0.80	0.80	1.16	1.24
Neck	0.15	0.15	0.11	0.16	0.30	0.30	0.40	0.65	0.65
Left Arm	0.33	0.33	0.22	0.23	0.40	0.40	0.90	1.00	0.89
Right Arm	0.33	0.33	0.23	0.23	0.40	0.40	0.86	1.00	0.89
Chest	0.90	0.93	1.07	1.34	1.60	0.60	2.25	5.55 ¹	6.39 ²
Gut	0.78	0.78	0.87	1.07	1.35	1.25	1.50	3.10	3.90
Left Thigh	0.45	0.45	0.20	0.21	0.75	0.80	0.80	1.20	1.76
Right Thigh	0.45	0.45	0.20	0.19	0.83	0.80	0.78	1.20	1.86
Left Calf	0.35	0.25	0.20	0.21	0.53	0.53	0.58	0.95	0.91
Right Calf	0.33	0.35	0.20	0.21	0.50	0.53	0.56	0.95	0.89
Total	4.45	4.68	4.16	4.83	7.47	6.40	9.43	16.76	19.38

¹ This is the sum of the two chest sections (3.00 + 2.55)

² This is the sum of the two chest sections (3.56 + 2.83)

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Full Weight Measurements (kg)

Section	PMA	PMB	PMF	PMC	PMD	PMG	PFA	FEB	PME
Head	4.53	4.40	4.25	4.23	4.20	4.22	3.50	3.47	4.24
Neck	1.25	1.25	1.35	1.70	1.14	1.28	1.48	1.49	1.57
Left Arm	4.75	4.85	5.00	4.10	4.85	5.12	2.74	2.84	4.41
Right Arm	4.78	4.60	5.00	4.45	4.82	5.14	3.03	3.49	4.65
Chest	19.15	18.65	19.20	20.10	19.45	20.02	14.97	15.20	18.69
Gut	12.98	12.88	11.60	11.60	11.30	11.16	9.29	9.40	9.76
Left Thigh	7.73	7.83	7.10	7.40	6.95	7.35	5.91	6.02	7.33
Right Thigh	7.68	7.75	7.10	7.60	6.92	7.22	5.75	5.97	7.23
Left Calf	4.80	5.10	4.60	4.65	4.53	5.27	3.64	3.75	4.51
Right Calf	5.08	5.08	4.70	4.55	4.55	5.25	3.59	3.78	4.67
Total	72.70	72.38	69.90	70.38	68.71	72.03	53.90	55.41	67.06

Full Weight Measurements (kg)

Section	P4A	P4B	P4C	P4D	PIOA	P1OB	PM5	PM95A	PM95B
Head	2.38	2.40	3.14	3.13	3.25	3.20	3.45	5.65	5.41
Neck	0.35	0.35	0.33	0.27	0.70	0.70	1.05	1.96	1.80
Left Arm.	0.95	0.95	0.91	0.90	1.90	1.93	3.55	6.90	6.12
Right Arm	0.95	0.98	0.98	0.93	1.83	2.00	3.36	6.80	6.02
Chest	4.60	4.58	5.96	6.14	10.10	10.05	16.45	35.17 ¹	34.62 ²
Gut	2.73	2.65	3.33	3.23	5.73	5.80	7.60	21.15	21.28
Left Thigh	1.70	1.70	0.81	0.83	3.93	4.10	5.23	9.25	9.03
Right Thigh	1.68	1.70	0.81	0.76	4.10	3.63	5.20	9.25	9.17
Left Calf	1.20	1.18	0.82	0.81	2.15	2.15	2.90	6.45	6.46
Right Calf	1.18	1.13	0.81	0.79	2.15	2.08	2.75	6.45	6.31
Total	17.71	17.60	17.91	17.79	35.83	35.63	51.54	109.03	106.22

¹ This is the sum of the two chest sections (22.00 + 13.17)

² This is the sum of the two chest sections (21.72 + 12.90)

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% by weight

Section	PMA	PMB	PMF	PMC	PMD	PMG	PFA	PFB	PME
Head	5.97	5.84	5.94	5.67	5.63	5.56	6.11	6.00	6.04
Neck	1.33	1.33	1.69	2.05	1.19	1.41	2.29	2.30	1.93
Left Arm	6.22	6.42	6.75	5.49	6.87	6.80	4.91	4.50	3.43
Right Arm	6.30	6.04	6.75	6.0	6.78	6.93	5.61	6.05	4.73
Chest	27.69	27.09	29.09	30.18	29.89	29.34	29.30	29.13	32.39
Gut	17.90	17.88	16.65	16.40	16.67	15.34	17.15	16.99	16.04
Left Thigh	10.70	10.88	10.29	10.60	10.05	10.26	11.02	10.86	31.11
Right Thigh	10.57	10.80	10.29	10.90	10.04	10.10	10.68	10.97	10.89
Left Calf	6.43	6.84	6.20	6.44	6.44	7.18	6.54	6.51	6.57
Right Calf	6.84	6.88	6.37	6.27	6.44	7.08	6.38	6.69	6.86

Section	P4A	P4B	P4C	P4D	P10A	P10B	PMS	PM95A	PM95B
Head	14.90	13.35	17.18	16.59	8.55	8.21	6.29	4.87	4.80
Neck	1.51	1.55	1.88	0.85	1.41	1.37	1.54	1.42	1.36
Left Arm	4.72	4.84	5.07	5.17	5.29	5.22	6.29	6.39	6.02
Right Arm	4.72	5.03	5.07	5.40	5.04	5.47	5.94	6.29	5.91
Chest	28.91	28.24	33.75	37.04	29.98	32.3	33.72	32.10 ¹	32.49 ²
Gut	14.71	14.51	17.30	16.67	15.43	15.5	14.49	19.56	20.01
Left Thigh	9.43	9.67	4.94	4.78	11.20	11.2	10.52	8.72	8.37
Right Thigh	9.24	9.67	4.94	4.40	11.55	9.67	10.5	8.72	8.41
Left Calf	6.41	7.16	4.94	4.63	5.73	5.56	5.51	5.96	6.39
Right Calf	6.45	6.00	4.94	4.48	5.82	5.30	5.20	5.96	6.24

1 This is the sum of the two chest sections (20.59 + 11.51)

2 This is the sum of the two chest sections (20.90 + 11.59)

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Characteristics of the modified PM chest section

Dimensions ¹ (cm)	2a	2b	h_1	h_2	h
PM _{acc2}	29.3	20.5	27.0	14.	41.5
PMD ³	29.7	20.2	-	-	41.9
	PM _{acc}		PMD		
Weights (kg)	Empty		Full	Empty	Full
Upper	3.45		14.02	-	-
Lower	3.45		9.08	-	-
Total	3.45		19.65	2.83	19.45

- 1 The dimensions of the upper and lower sections of the modified chest section are denoted by h_1 and h_2 respectively.

PM_{acc} is the acronym for PM-accessory

- 3 Dimensions of PMD are shown for comparison.



PHANTOM PRICE INDEX

Prices are in US funds

Man	\$3967.50
Man (5%)	\$3979.00
Man (95%)	\$4232.00
Woman	\$3910.00
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